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Salmonid Smoltification and Early Marine Survival

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On the cover: Smolting coho salmon, *Oncorhynchus kisutch*. Photographs by Bernard Nist, Seattle, Wash. See the article beginning on page 1.

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Environmental Factors Affecting Smoltification and Early Marine Survival of Anadromous Salmonids

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ABSTRACT—An important requirement in the efficient use of artificially propagated juveniles for salmon enhancement programs is that the resulting smolts be fully prepared behaviorally and physiologically to migrate to sea and continue to grow and develop normally. In this paper, physiological criteria for identifying fully functional smolts are presented and environmental factors are identified which will influence smoltification, and thus early marine survival. Methods are described for optimizing time, age, and size at release, and data are presented on methods of environmental manipulation to alter smoltification to fit specific resource management needs. On the basis of our present understanding of the physiology of the parr-smolt transformation and of the influence of environmental alterations during rearing, guidelines are presented for management strategies to improve survival of Pacific, Oncorhynchus *sp., and Atlantic salmon,* Salmo salar, *and anadromous (steelhead) rainbow trout,* Salmo gairdneri.

Introduction

A perennial problem in the efficient use of artificially propagated juveniles in salmon enhancement programs and in aquaculture is that ocean survival often has been below estimated survival of naturally produced smolts even though hatcheries can consistently outperform nature in survival through the hatching and early developmental stages. For example, Saunders and Allen (1967) estimated that survival to adults of wild, unmarked Atlantic salmon, *Salmo salar,* smolts in the Miramichi River, New Brunswick, was no less than 8 percent and possibly as high as 32 percent. Allowing for the detrimental effects of tagging, few plantings of hatchery Atlantic salmon have come close to these values, although survival of hatchery coho salmon, *Oncorhynchus kisutch,* to adults can be as high as 45 percent under optimal conditions;[1] however, it is more often less than 10 percent. Experience in both Europe and North America shows that, within limits, survival through to adult returns tends to be directly proportional to size-at-release (Carlin, 1969; Ritter, 1972; Peterson, 1973). Accordingly, most hatcheries release large smolts in an attempt to increase contribution to the fishery and returns to the hatchery. However, Bilton (1978) has shown that release of very large coho smolts caused an increased incidence of precocious males and reduced adult returns.

There is reason to suspect that in many cases apparently healthy hatchery fish, though large and silvery, are not actually functional smolts and their limited contribution to the fishery, even when stocked into the same rivers from which their parents were taken, results from their being unprepared to go to sea. This failure to produce good quality smolts probably arises from an incomplete understanding of exactly what constitutes a smolt, as well as from a lack of understanding of the environmental influences that affect the parr-smolt transformation and which may lead, as a long term consequence, to reduced ocean survival. There are many case histories describing poor performance following release of juveniles which, although clinically healthy and large enough to be smolts, apparently did not have complete smolt physiology and behavior. Gudjonsson (1972) reported that initial attempts to produce yearling Atlantic salmon in an Icelandic hatchery supplied with heated (geothermal) water resulted in the release of large healthy juveniles but no adult returns. Many remained in the stream during the summer following release. These "smolts" had been reared indoors under a constant, artificial light photoperiod and did not show normal migratory behavior. However, a similar group that had been held outside the hatchery under a natural (increasing) photoperiod showed normal migratory behavior and good adult returns. Subsequent work with natural or artificial light under a simulated natural photoperiod resulted in normal migration and adult returns (Isaksson, 1973, 1974, 1976).

A second case history report of detrimental environmental effects occurred at the Craig Brook (Maine) National Fish Hatchery.[2] In this case, Atlantic salmon in open, shallow raceways became silvery and showed smolt behavior as early as February. Subsequently many fish developed dorsal epidermal lesions and died. This condition is often referred to as "sunburn." Releasing the surviving fish in late May, the usual smolt release time, gave few adult returns. This problem was overcome by shielding the raceways from direct sunlight.

In these two examples involving Atlantic salmon, poor smolt development probably resulted from an unnat-

[1] H. T. Bilton and T. Alderdice, Research Scientists, Pacific Biological Station, Nanaimo, B.C., Canada, pers. commun. June 1979.

[2] Roger Dexter, Fishery Biologist, U.S. Fish and Wildlife Service, Craig Brook National Fish Hatchery, Orland, Maine, pers. commun. February 1979.

ural day length (photoperiod) and from high light intensity, respectively.

This review paper will describe the physiological and behavioral criteria used to distinguish Atlantic and Pacific (*Oncorhynchus* sp.) salmon, and steelhead trout, *Salmo gairdneri,* smolts from parr; discuss the influences of environmental conditions on smoltification and subsequent early marine survival; and conclude with guidelines for management strategies to maximize survival and potential contribution to the fishery.

Physiological and Behavioral Criteria for Smolt Status

Body Silvering, Fin Darkening

A summary of the physiological changes occurring during the parr-smolt transformation of anadromous salmonids is given in Table 1. Among the many changes which occur, the external body silvering, and fin margin blackening (in Atlantic salmon, coho salmon, and steelhead trout) are among the most dramatic characteristics used to distinguish smolts from parr. The silvery color results from deposition of guanine and hypoxanthine crystals in the skin and scales. These are products of protein catabolism and their seasonal appearance reflects changes in the dynamics of protein metabolism. Early studies showed that thyroid hormone was somehow involved in the silvering process (Landgrebe, 1941). Piggins (1962) found that feeding beef thyroid gland resulted in body silvering of Atlantic salmon parr. Dodd and Matty (1964) reported that alevins (Atlantic salmon) would become silvery if thyroxine was added to the water. Cortisol has also been demonstrated to cause silvering in the eel, *Anguilla anguilla* (Epstein et al., 1971; Olivereau, 1972). Johnston and Eales (1970) found that silvering during smoltification of Atlantic salmon is greater on large than on small parr and that water temperature influences silvering more than photoperiod. In naturally produced Atlantic salmon smolts, particularly, the caudal and pectoral fin margins become black. This characteristic helps to differentiate silvery parr, often seen in the early part of the out-migrant run, from true smolts. However, coloration by itself is not an adequate criterion for smolting in either Atlantic or Pacific salmon, especially in hatchery fish. Though silvering and fin blackening may be a good indication of smolt status in wild fish, these colors often develop in hatchery parr when the fish are not otherwise smoltlike. Clearly, additional physiological criteria are necessary.

Table 1.—Physiological changes occurring during the parr-smolt transformation of Pacific (*Oncorhynchus* sp.) and Atlantic salmon, *Salmo salar,* and steelhead trout, *Salmo gairdneri.* All of these changes must be properly coordinated to ensure adequate smolt functionality and health.

Physiological characteristics	Level in smolts compared with parr
Body silvering, fin margin blackening	Increases
Hypoosmotic regulatory capability	Increases
Salinity tolerance and preference	Increases
Weight per unit length (condition factor)	Decreases
Growth rate	Increases
Body total lipid content	Decreases
Oxygen consumption	Increases
Ammonia production	Increases
Liver glycogen	Decreases
Blood glucose	Increases
Endocrine activity	Increases
Thyroid (T_4)	
Interrenal	
Pituitary growth hormone	
Gill microsome, Na^+, K^+-ATPase enzyme activity	Increases
Ability to grow well in full-strength (35‰) sea-water	Increases
Buoyancy (swim bladder, Atlantic salmon)	Increases
Migratory behavior	Increases

Hypoosmotic Regulatory Capability, Salinity Tolerance, and Preference

Perhaps the major physiological process of the smolting phenomenon is the increase in hypoosmoregulatory ability which preadapts the fish to life in seawater (Folmar and Dickhoff, in press). Associated ionoregulatory changes have long been recognized to occur in fresh water and include a decrease in plasma and tissue chloride (Fontaine, 1951; Houston, 1960; Houston and Threadgold, 1963), a decrease in glomerular filtration rate (Holmes and Stainer, 1966), and, more recently, a dramatic increase in gill Na^+, K^+-ATPase activity (Zaugg and McLain, 1970; McCartney, 1976; Saunders and Henderson, 1978). However, salinity tolerance or ability to survive in seawater cannot by itself be used to distinguish smolts from parr. Juvenile steelhead trout and coho and Atlantic salmon develop seawater tolerance before the smolting process is complete (Conte and Wagner, 1965; Conte et al., 1966; Wagner, 1974b; Farmer et al., 1978). Nevertheless, the hypoosmoregulatory ability of parr can be distinguished, physiologically, from that of true smolts during the process of adaptation to seawater (Parry, 1960; Houston, 1959, 1961; Clarke and Blackburn, 1977, 1978). Recently, Komourdjian et al. (1976a) and Saunders and Henderson (1978) showed that a challenge with high salinity (40‰) reveals a degree of salinity tolerance in Atlantic salmon smolts that is undeveloped before smoltification and which is an excellent indication of smolt status and preparedness for hypoosmotic regulation.

Salinity tolerance is also influenced by size (Parry, 1960). In species such as Atlantic salmon, steelhead trout, and coho salmon, hypoosmoregulatory capacity increases with growth until smolting occurs. However, if the smolts are prevented from entering seawater, their ability to adapt to it then decreases, despite continued growth (Evropeitseva, 1957; Koch, 1968; Zaugg and McLain, 1970). This phenomenon (designated as desmoltification in freshwater, parr-reversion in salt water) has been suggested as one reason for the frequently lower growth rates of landlocked compared with sea-run salmon (Koch, 1968; Saunders and Henderson, 1969). However, Saunders and Henderson (1969) observed a growth rate inversely related to salinity and no increased mortality of Atlantic salmon held past the smolt stage in freshwater. They concluded that stunting of landlocked Atlantic salmon was more likely due to inadequate food supply in fresh water than to salinity per se. In "non-smolting" species such as nonanadromous rainbow trout, *Salmo gairdneri,* continued growth appears to confer increased seawater adaptive efficiency (Houston, 1961; Landless and Jackson, 1976).

The seasonal increase in salinity tolerance of salmonids is well known, and peak hypoosmotic regulatory ca-

pability generally is thought to coincide with smolt migratory behavior. Periodic seawater challenge tests have demonstrated that the hypoosmoregulatory ability of juvenile Atlantic, as well as coho salmon, peaks at the time of smolting (Komourdjian et al., 1976b; Boeuf et al., 1978; Clarke and Blackburn, 1978). On the other hand, certain populations of anadromous salmonids may initiate migration before they are able to adapt to full strength seawater (Clarke and Blackburn, 1978). However, smolting is a necessary prerequisite for juvenile salmon to continue to grow well after conversion to seawater. Saunders and Henderson (1970) observed supressed feeding behavior and growth of juvenile Atlantic salmon transferred to seawater after being exposed to an unnatural photoperiod regimen, which disrupted the smolting process. Similarly, transfer of juvenile coho salmon to seawater before they are fully smolted causes dramatic suppression of growth; these stunted fish also show a number of endocrine abnormalities (Clarke and Nagahama, 1977).

Houston (1960) reported reduced tissue Na^+ concentrations in Atlantic salmon at the time of smolting. Fontaine (1951) found low tissue Cl^- levels, while Houston and Threadgold (1963) noted increased tissue water content at smolting; both indicative of a shifting pattern of water and ion regulation. These observations suggested that a Na^+,Cl^- pump had begun operation while the fish were still in fresh water. Houston and Threadgold (1963) noted an increase in number and apparent activity of the Keys-Willmer (chloride) cells of salmon in seawater. Van Dyck (1966) found increased activity of Keys-Willmer cells during smolting and decreased activity during desmoltification if the salmon were not allowed to migrate. Hoar (1951) reported that injection of mammalian anterior pituitary extract in Atlantic salmon parr resulted in stimulation of these supposed Cl^- secretory cells.

Growth Rate, Condition Factor

Two other features which have proven to be helpful indicators of smolt status are growth rate and condition factor. Saunders and Henderson (1970) and Komourdjian et al. (1976b) showed that Atlantic salmon smolts, whether naturally smolted or induced to smolt by manipulation of photoperiod, have a higher growth rate than nonsmolts. Komourdjian et al. (1976a) also showed that salmon parr which had received injections of porcine growth hormone every other day for 4 weeks showed both increased growth rates and greater salinity tolerance than placebo injected controls. The use of condition factor as an indicator of smolt status is based on the fact that the length-weight relation is typically low in wild smolts; that is, smolts typically weigh less per unit length than do parr. Wagner (1974a) has successfully used decreased condition factor as a criterion of smolting in steelhead trout. Saunders and Henderson (1970) and Komourdjian et al. (1976a) found that the condition factor of Atlantic salmon also decreased at the time of smolting or as a result of growth hormone injection.

Body Composition, Lipid-Moisture Dynamics, Carbohydrate Metabolism

Another physiological change during smoltification, which has long been used as a criterion, is the reduction in total body lipid. This is undoubtedly related to the other metabolic parameters which show characteristic alterations during the parr-smolt transformation. Recently, Komourdjian et al. (1976b) have demonstrated this effect in Atlantic salmon induced to smoltify during winter by artificially increased day length. Total lipid content was significantly lower than in the nonsmolted controls held under a simulated natural photoperiod. The criteria of smolting used were silvering, growth rate, salinity tolerance, and increase in number and apparent activity of pituitary growth hormone cells as revealed by histological examination. Coincident with falling lipid levels, total moisture content increases during smoltification (Komourdjian et al., 1976b; Farmer et al., 1978; Saunders and Henderson, 1978). Reduced lipid and increased moisture content probably reflect metabolic changes that accompany smolting. Withey and Saunders (1973) confirmed experimentally that photoperiod manipulation to retard smoltification resulted as well in lower standard oxygen consumption rates, compared with fish of similar age under natural photoperiods.

An altered carbohydrate metabolism is also characteristic of the parr-smolt transformation. Early work by Fontaine and Hatey (1950) and Malikova (1957) showed that reduced liver glycogen accompanied an accelerated protein and lipid catabolism. More recently, Wendt and Saunders (1973) found both reduced liver glycogen and elevated blood glucose levels in hatchery reared Atlantic salmon during smoltification. At the same time of year, the salmon parr had high liver glycogen levels, low blood glucose, and, unlike smolts, survived transport without sharp reverses in these carbohydrate levels. Wedemeyer (1972) showed that the stress of handling smolting coho salmon caused severe hyperglycemia, hypochloremia, and the activation of subclinical kidney disease infection. Carbohydrate metabolism of coho parr was much less affected by the stress of hatchery practices.

Endocrine Control

A number of endocrine changes have been observed during the parr-smolt transformation; chiefly, an activation of thyroid, interrenal, and pituitary growth hormone cells. Hoar (1939) first observed increased thyroid cell activity (by histological examination) in Atlantic salmon at the time of smolting and this has since been confirmed in other anadromous salmonids (Robertson, 1948; Baggerman, 1960). Recently, Dickhoff et al. (1978) and Folmar and Dickhoff (1979) have measured very high plasma thyroid hormone concentrations in coho smolts. As a practical application, oral administration of thyroidal materials, particularly triiodothyronine, shows considerable promise as a technique for stimulating growth and smolting of cultured salmon (Piggins, 1962; Higgs et al., 1977).

The pituitary-interrenal axis, as judged by histological evidence, is also

known to be activated at the time of smolting in Atlantic and Pacific (coho) salmon (Fontaine and Olivereau, 1959; Olivereau, 1962, 1975; McLeay, 1975; Komourdjian et al., 1976b). Evidence for an involvement of pituitary growth hormone in the smolting process is derived from both physiological and histological studies. First of all, it has long been recognized that a period of rapid growth accompanies the smolting process and secondly, that there is a strong correlation between growth rate and smolting tendency (Parry, 1958; Houston and Threadgold, 1963; Conte, 1969; Saunders and Henderson, 1970; Komourdjian et al., 1976b; Ewing et al., in press).

The first direct evidence for an effect of growth hormone was provided by Smith (1956) who reported that injections of mammalian growth hormone enabled brown trout, *Salmo trutta,* to survive in seawater. Since then, Komourdjian et al. (1976a) have demonstrated that injections of porcine growth hormone enable Atlantic salmon parr to survive in seawater. Similarly, Clarke et al. (1977) demonstrated that injections of either bovine or teleost growth hormone improve the hypoosmoregulatory performance of underyearling sockeye salmon. Histological changes in the pituitary growth hormone cells were first described in Atlantic salmon smolts by Olivereau (1954). More recently, Komourdjian et al. (1976b) demonstrated experimentally that holding Atlantic salmon parr under a long photoperiod during winter promoted growth, and accelerated the development of smolt characteristics, including an increase in the number and granulation of pituitary growth hormone cells. In coho smolts, hypertrophy as well as hyperplasia of the growth hormone cells has been observed (Clarke and Nagahama, 1977).

Further studies are needed to clarify the functions of growth hormone and other hormones in coordinating the smolting process (Bern, 1978). Particularly intriguing is the possible role of prolactin, which is known to influence the osmoregulatory capability of salmon in freshwater; however, little is known about its function in smolts (Ball, 1969). Zambrano et al. (1972) observed a decrease in the activity of the pituitary prolactin cells in smolting Pacific salmon (*O. masou*) in freshwater but no similar changes have been observed in smolting Atlantic salmon prior to seawater entry (Komourdjian et al., 1976b). The activity of the prolactin cells in coho salmon also appears considerably lower after acclimation to seawater (Clarke and Nagahama, 1977; Nagahama et al., 1977).

Na^+, K^+-ATPase Activity

One of the important changes taking place during salmonid smolting is an increase in the Na^+, K^+-activated ATPase enzyme activity of the gill microsomal system (Zaugg and McLain, 1970; Zaugg and Wagner, 1973; McCartney, 1976; Giles and Vanstone, 1976; Saunders and Henderson, 1978). The gill ATPase system is involved, directly or indirectly, in excretion of monovalent ions from the blood. Salmonids and other euryhaline fishes typically show increased ATPase and ion pump activity prior to and following adaptation to seawater (Epstein et al., 1967; Kamiya and Utida, 1969; Kamiya, 1972). The increase in ATPase activity begins in salmonids during smoltification, prior to their entry into seawater and peaks near the time they show typical "smolt behavior" in a hatchery, or the most active migratory behavior in a stream (Fig. 1). If the smolts are allowed entry to seawater, ATPase activity continues to rise and stabilizes at an elevated level (Folmar and Dickhoff, 1979). If the smolts are not allowed to migrate, enzyme activity will gradually decline to initial levels as desmoltification occurs.

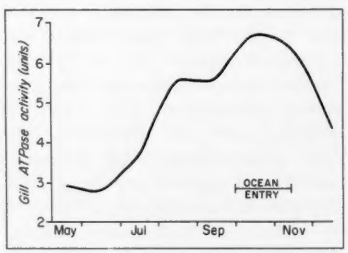

Figure 1.—Gill Na^+, K^+-ATPase activity in juvenile spring chinook salmon over a 2-year period. This chinook salmon race normally enters the ocean from the Rogue River (Oregon) in September-October (redrawn from Ewing et al., in press).

Buoyancy Adjustment

In addition to the physiological aspects of smolting, several behavioral changes distinguish smolts from parr. Atlantic salmon parr are territorial and live on or near the stream bottom, whereas smolts tend to develop schooling behavior and swim at middepth (Kalleberg, 1958). The physiological basis of this difference is not fully understood. However, salmonids are physostomous and fill their swim bladder by swallowing air. Saunders (1965) and Pinder and Eales (1969) demonstrated that smolts maintain larger volumes of air in their swim bladders than do parr, and therefore are more buoyant despite their reduced lipid content. Increased buoyancy could result in more difficulty maintaining a position on a stream bottom, and may have some influence in initiating downstream movement. This behavioral response is probably at least one of the factors involved in the change from a predominantly bottom living existance to a pelagic one (Saunders, 1965).

Another behavioral pattern is the development of preference for increased salinities. Baggerman (1960) and McInerney (1964) first reported seasonal changes in salinity preference of juvenile Pacific salmon presented with a horizontal salinity gradient. Baggerman also demonstrated that salinity preference was affected by photoperiod, and suggested that endocrine activity, controlled by environmental priming factors, was involved.

Migratory Activity

Perhaps the most dramatic behavioral change shown by smolts is downstream migration. Migratory activity has long been used as an index of smolt status. However, as with the other criteria, it has limitations. Baggerman (1960) originally developed the model of diadromous fish migrations in which

environmental "priming" factors such as day length and temperature condition the smolts physiologically, mainly through the pituitary, to prepare for migration. External "releasing" factors such as light intensity and river flow rates finally trigger migrations. In the George and Koksoak Rivers at the northern end of the Atlantic salmon range in Labrador, salmon sometimes "smoltify" during several successive years before finally leaving the rivers (Power, 1959). The seawater migrating smolts are commonly 6 years old and longer than 20 cm. They may represent an incipient landlocked population. On the other hand, it is entirely possible that, under the extreme environmental conditions at the northern end of the Atlantic salmon range, coordination of the several physiological and behavioral processes that constitute smoltification is imperfect, particularly with the slow growth that occurs. In this area of Labrador, the ice persists well into the summer, and seawater temperatures remain low. From this and other case history observations, Koch (1968) concluded that smoltification and migration may have separate causes.

A practical application of the relation between smolting and migratory behavior has been the use of delayed smolt releases from hatcheries to obtain "non-migrating" populations of Pacific salmon in Puget Sound (Mahnken and Joyner, 1973). It was first observed that coho salmon that escaped from saltwater net pens in late summer did not leave the general area. More recently, chinook salmon as well have been induced to form residual populations by delaying release until after the usual migration time.

Size Threshold

A final criterion to consider is the influence of body size on smolting. Allen (1944) and Elson (1957) early emphasized the importance of size in Atlantic salmon smoltification. Pinder and Eales (1969) and Johnston and Eales (1970) found that buoyancy development and silvering both proceeded faster and to a greater degree in larger than in smaller parr. Conte and Wagner (1965) noted a significant size dependence in salinity tolerance in Pacific salmon and steelhead trout. In wild Atlantic salmon, the minimum size threshold for smolting appears to be 12-13 cm, although most smolts are in the 14-17 cm range. However, they may range in age from 2 to as much as 5 years. Although smaller salmon may be silvery, have a certain degree of salinity tolerance, and show increased buoyancy at smolting time, other aspects, especially migratory behavior, do not develop until the following year after the threshold size has been reached. It appears that, although several of the components of smolting exist in very small salmon, the needed physiological coordination is lacking.

In summary, considerable progress has been made, but much additional information is still needed if biologists are to be able to explain fully the phenomenon called smolting and control it to increase efficiency in the use of artificially propagated juveniles in salmon enhancement programs.

The word "smolting" has been used to describe the physiological and behavioral preadaptation of salmonids for movement between the nursery rivers and the sea. However, it is perhaps unfortunate that the term is used in this sense. The result has been to encourage the belief that several separate physiological processes must take place before smolting is complete.

A more functional view is that smolting is the coordination of several, separate, physiological and behavioral processes, including downstream migration, resulting in the ability to continue to grow and develop normally in the ocean. For example, in Atlantic salmon these processes allow the change, from a bottom dwelling territorial fish in freshwater to a pelagic, loosely schooling fish in the sea. Some of these changes are in progress well before smolting time, some are in response to recognizable environmental stimuli, and perhaps all of them have an endogenous rhythm. In Atlantic and Pacific salmon, photoperiod has been identified as the major environmental priming factor and coordinator which brings these endogenous physiological processes together on a temporal basis. There are ample experimental data to show that body silvering, fin darkening, salinity tolerance and preference, growth rate, growth hormone cell activity, gill ATPase activity, and lipid metabolism can be activated, postponed, advanced, or coordinated by photoperiod manipulation. Water temperature acts as the major controlling factor setting the range within which these processes can go on and, within these limits, determining their rates of reaction (Clarke, Shelbourn, and Brett, 1978).

Environmental Factors Affecting the Parr-Smolt Transformation

Contaminant Exposure

It has recently been shown that alterations of water chemistry can have a major deleterious effect on smoltification and early marine survival. One example of this phenomenon, which has particularly serious resource management consequences, is the effect of trace heavy metal exposure during rearing; normally due to mineral deposit drainage or to non-point-source industrial pollution (Lorz and McPherson, 1976). Unfortunately, the gill ATPase enzyme system of smolts and presmolts is sensitive to levels of dissolved heavy metals currently considered to be within the maximum safe exposure limits for freshwater fish populations. For example, wild coho salmon juveniles normally become migratory during the spring of their second year but are euryhaline somewhat before this time if they have reached a threshold size of about 9 cm (Conte et al., 1966). Chronic copper exposure during the parr-smolt transformation, at only 20-30 μg/l, partially or completely inactivates the gill ATPase system (Lorz and McPherson, 1976). The biological damage is not apparent unless the fish are moved into saltwater, at which time severe mortalities begin. A more subtle but equally devastating consequence is that normal migratory behavior is also suppressed. Similar results were obtained by Davis and Shand (1978) using sockeye salmon. Laboratory exposure of smolts for 144 hours to copper at 30 μg/liter impaired hypoosmoregulatory

performance, as revealed by a seawater challenge test, and resulted in some mortality.

Cadmium levels of more than 4 μg/liter in freshwater also result in a dose-dependent mortality if exposed coho smolts are transferred directly into 30‰ seawater (Lorz, Williams, and Fustish, 1978). However, if a 5-day freshwater recovery period is allowed before saltwater challenge, survival returns to normal. In contrast to copper, sublethal cadmium or zinc exposure during rearing apparently does not adversely affect migratory behavior. However, if even very low levels of copper (10 μg/l) are simultaneously present, downstream migration is reduced, and normal gill ATPase activity is suppressed. Unfortunately, few apparent alterations in growth or in feeding behavior occur to act as a warning and the smolts appear to be "normal" when released.

Nickel or chromium exposure at up to 5 mg/liter for 96 hours in freshwater apparently does not compromise migratory behavior or capability for ocean survival but sublethal mercury exposure results in a dose-dependent seawater mortality (Lorz, Williams, and Fustish, 1978). The fact that coho smolts would be unable to migrate directly into the ocean would probably tend to increase their residence time in the river and estuary—with consequent exposure to predation and diseases such as *Vibrio* and viral erythrocytic necrosis (VEN).

Less is known about the effects of low-level heavy metal exposure on smoltification and migration of salmon such as sockeye, pink, chum, or fall chinook, which have much different freshwater behavior patterns. However, Servizi and Martens (1978) reported that mortality, hatching, and growth of sockeye salmon during the egg to fry stage were not affected by continuous exposure to 5.7 μg/liter cadmium. However, the 168 hour LC_{50} decreased from 4,500 to 8 μg/liter as development from the alevin to fry stage occurred. For copper, the incipient lethal level during the egg to fry stage was within the range of 37 to 78 μg/liter for sockeye salmon and 25 to 55 μg/liter for pink salmon. Copper inhibited egg capsule softening, but hatching mortality occurred only at concentrations also lethal to eggs and alevins. Dissolved copper was concentrated by eggs, alevins, and fry in proportion to exposure concentrations. For pink salmon, mortalities of eyed eggs and fry occurred when tissue copper concentrations reached levels of 105 and 7 mg/kg, respectively.

For (inorganic) mercury exposure, concentrations of only 2.5 μg/liter caused development of malformed embryos. Hatching success, fry mortality, and growth were less sensitive to mercury exposure than was malformation. Mercury was also concentrated by sockeye and pink salmon eggs, and embryo abnormalities occurred when concentrations reached about 1.9 mg/kg.

In addition to trace heavy metal exposure, normally due to drainage from mineral deposits, or to non-point-source industrial pollution, increasingly intensive forest, range, and agricultural practices are resulting in chronic low-level herbicide concentrations in many juvenile salmon rearing waters. Coho salmon smolts exposed for only 96 hours to the herbicide Tordon 101[3] at 0.6-1.8 mg/liter just prior to release did not migrate as successfully as the control group (Lorz, Glenn, Williams, Kunkel, Norris, and Loper, 1978). Tordon 101 is a formulation of picloram and the dimethylamine salt of 2,4-D used for brush, weed, and vine control on noncrop lands, including rights of way. Other 2,4-D and 2,4,5-T formulations, such as the esters used for Eurasian water milfoil control, may also inhibit smolt function and migratory behavior. Low level 2,4-D exposure is known to cause an avoidance response in nonanadromous steelhead trout (Folmar, 1976). The potential for such deleterious effects should be ruled out before extensive herbicide applications are made.

Water Temperature

Elevated water temperatures are sometimes used to accelerate growth and shorten the normal time needed to produce smolts (Saunders, 1976). However, such artificial temperature regimes must be used with care because they can influence the smolting process itself as well as growth. Rearing temperature has a strong influence on the pattern on hypoosmoregulatory ability and gill ATPase activity development during smolting. In certain species, elevated temperature can not only accelerate the onset of smolting but also hasten the process of desmoltification so that the duration of the smolting period is shortened (Fig. 2). Coho salmon show a slow, sustained rise in gill ATPase activity at 6°C, a more normal pattern at 10°C, and a precocious development pattern at temperatures up to 20°C (Zaugg and McLain, 1976). Temperatures up to 15°C have been used to accelerate the smolting process so that juvenile coho salmon can be introduced to seawater in their first year; however, as shown in Figure 2, desmoltification is also accelerated (Novotny, 1975; Donaldson and Brannon, 1976; Clarke and Shelbourn, 1977). Juvenile fall chinook salmon also undergo a more rapid reversion to the parr condition at elevated holding temperatures (Clarke and Blackburn, 1977). The problem of accelerated desmoltification during rearing at elevated temperature can be overcome by holding sockeye, coho, or chinook salmon smolts in dilute seawater at salinities of 10-20‰ (W.C. Clarke, unpubl. data).

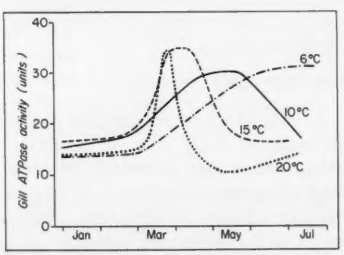

Figure 2.—Summary of the effect of water temperature on the pattern of gill Na^+, K^+ ATPase activity development of juvenile coho salmon (redrawn from Zaugg and McLain, 1976).

[3]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

However, not all salmonids are amendable to temperature acceleration of smolting. Steelhead trout are particularly sensitive to the elevated rearing temperature sometimes used to accelerate growth (Fig. 3) and smolting can be inhibited at 13°C and above (Adams et al., 1973, 1975; Zaugg and Wagner, 1973). Laboratory experiments have shown that Atlantic salmon apparently smolt at temperatures as high as 15°C (Saunders and Henderson, 1970; Komourdjian et al., 1976b). However, until the temperature dependence of salinity tolerance development has been fully characterized, it is prudent to assume that Atlantic salmon are not unlike steelhead trout. In this regard, it may be significant that native runs of Atlantic salmon show their greatest downstream migrant activity as the temperature rises to 10°C. Smolt runs are over before the water warms to 15°C or more.

Photoperiod

Hoar's (1965) summary of the physiological and behavioral aspects of salmonid smolting cites the endocrine system as the chemical link between environmental changes and physiological changes in the fish. The seasonal cycle of growth and smolting in juvenile salmon has a strong endogenous component which is synchronized by the yearly photoperiod cycle (Hoar, 1965, 1976; Poston, 1978). This endogenous component has been demonstrated by the occurrence of asynchronous smolting under either continuous short photoperiods (Hoar, 1965) or complete darkness (Wagner, 1971). In a detailed series of experiments, Wagner (1971, 1974a) demonstrated that the photoperiod cycle synchronized the development of smolt characteristics and migratory behavior in juvenile steelhead trout. He found that the rate of change of photoperiod was an important cue, and that attempts to modify the timing of smolting were more successful if a shift in phase of the photoperiod cycle was used, rather than a change in its frequency. On the other hand, 30-day survival in seawater was not closely associated with smolting and was not influenced by photoperiod (Wagner, 1974b). In line with this, Clarke, Folmar, and Dickhoff (1978) found that presmolts held for 2 weeks under a 17-hour light, 7-hour dark photoperiod (17L:7D) had significantly higher gill ATPase and plasma thyroxine (T_4) levels, and were better able to regulate plasma Na^+ than were fish held under an 8L:16D photoperiod. However, after only 7 days in seawater, there were no differences between the groups. Experiments with juvenile Atlantic salmon have demonstrated that the spring growth acceleration, as well as smolting, can be advanced by several months if an increasing or long photoperiod is applied during winter (Saunders and Henderson, 1970; Knutsson and Grav, 1976; Komourdjian et al., 1976b). Photoperiod also has a marked effect on the growth and hypoosmoregulatory ability of underyearling sockeye and coho salmon (Clarke and Shelbourn, 1977; Clarke, Shelbourn, and Brett, 1978). Again, the most important photoperiod cues were shown to be direction and rate of change of day length, not day length per se. Prolonged exposure to a long photoperiod inhibits growth and smolting (Wagner, 1974a; Clarke, Shelbourn, and Brett, 1978). The role of temperature is to control the rate of physiological response to photoperiod such that effects are apparent sooner at elevated temperatures.

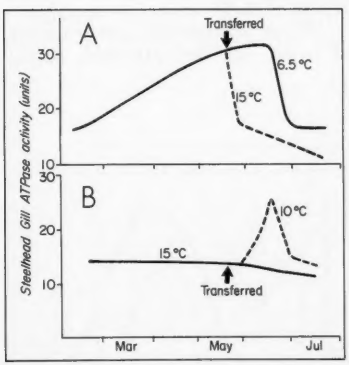

Figure 3.—Effect of water temperature on gill Na^+, K^+-ATPase activity of yearling steelhead trout. A. Held at 6.5°C, and transferred to 15°C (arrow). B. Held at 15°C and transferred to 10°C (arrow); ATPase development then occurred. (Redrawn from Zaugg et al., 1972.)

Hatchery Practices, Fish Disease Treatments

The smolt performance problems associated with the economic requirements for intensive, rather than extensive, fish culture for salmon enhancement programs have led to the widely held belief that improvements in present hatchery practices will contribute substantially to increased ocean survival and returns to the fishery. Two major areas have been identified. First, the fish cultural methods themselves. For example, a supression of normal ATPase development in juvenile chinook salmon by high population densities has recently been noted, although no data are yet available for other fishes (Strange et al., 1978). Second, certain fish disease therapeutants, including several drugs and chemicals commonly used pre-release, are now known to inhibit the seawater tolerance of smolts (Bouck and Johnson, 1979).

For clinically healthy coho salmon smolts treated and then transferred directly to 28‰ seawater for 10 days, Bouck and Johnson (1979) found low or no mortality following treatment with trichlorofon, simazine, or quinaldine. About 10 percent mortality occurred in groups treated with Formalin and nifurpirinol. High seawater mortality rates occurred following treatments with copper sulfate, hyamine 1622, potassium permanganate, malachite green, and MS-222. If a 4-day freshwater recovery period was allowed, mortality was reduced for copper sulfate, potassium permanganate, MS-222, and malachite green; much lower for hyamine 1622; and nil for the other agents. Thus the laudable effort to release fish free of external parasites and subclinical bacterial infections can potentially result in the release of disease free, but nonfunctional smolts. These findings, which are summarized in Table 2, suggest that it would be good practice to allow a 2-week freshwater recovery period when smolts are

Table 2.—Summary of seawater survival of coho salmon smolts following standard treatments with drugs and chemicals commonly used in fish culture (Bouck and Johnson, 1979).

Chemical	Treatment			Total mortality (%) during 10-days in seawater	
	Concentration of active ingredient (mg/l)	Length of daily exposure (min)	Consecutive days treatment was given	Direct transfer into seawater following treatment	Treatment, then 4-days in fresh water, then 4-hours acclimation to seawater
Controls	none	none	none	0 4	0
Copper sulfate	37	20	1	100	20
Endothal	5	60	1	100	4
Formalin	167	60	1	12	0
Hyamine 1622	2	60	4	68	4
Malachite green	1	60	1	44	12
MS-222	100	6	1	100	12
Nifurpirinol	1.5	60	4	8	0
Oxytetracycline	1	60	1	20	12
Potassium permanganate	2	60	3	80	12
Quinaldine	2.5	10	1	0	0
Simazine	2.5	60	1	4	0
Trichlorofon	0.5	60	1	0	0

given any pre-release disease treatment. For hatcheries sufficiently distant from the sea, the period of river migration might suffice.

Methods for Optimizing Time, Age, and Size at Release

Management strategies for optimizing ocean survival and total returns to the fishery must center around the production and release of functional, healthy smolts at the most favorable size, age, and time. Historically, hatchery releases have been timed to mimic the migration of resident wild salmonids in the rivers in question. However, in many waterways there have been mild to severe changes in the aquatic environment which now render historical migration times inappropriate. These include the occurrence of gas supersaturation in the spring, restrictions on stream flows due to the requirements of intensive agricultural and hydropower generation, and fluctuations in temperature and food supplies in river, estuarine, and coastal areas. In addition to these factors, the genetic composition of the hatchery fish in any particular river may have been changed significantly from that of the wild type due to the practice of importing eggs from stocks in other watersheds and the (sometimes inadvertent) genetic selection that occurs during hatchery egg taking operations. Superimposed on these problems are constantly evolving needs of resource management programs, such as the recent development of ocean ranching, or delayed releases used to establish resident salmon populations in local marine areas.

There have been relatively few studies that have separated the effects of smolt size from time of release on the number of returning adult salmon. Peterson (1973) found that 2-year-old Atlantic salmon out-migrant smolts smaller than 14 cm gave low adult returns. Greater numbers of returning adults were obtained as smolt length increased from 14 to 18 cm. Above a fish size of 18 cm, returns again tapered off. In contrast, yearling smolts showed good adult returns at release lengths of 12.5 to 14 cm (Peterson, 1973). This difference between the two age classes indicated that size is not an absolute factor in determining marine survival. Perhaps growth rate is more important.

For coho salmon, time of release, for a given smolt size, also has a profound effect on marine survival. Bilton (1978) investigated this phenomenon by releasing smolts graded into several size categories over a period of 4 months. He found that the optimal size varied with time of release and that maximum return of adult salmon resulted from the release of smolts of approximately 20 g, just prior to the summer solstice. Very large smolts were associated with more precocious males (jacks) in the population and thus a reduced total adult biomass.

ATPase Test

Dramatically increased gill Na^+,K^+-stimulated adenosinetriphosphatase activity has been associated with the parr-smolt transformation in salmonids for some time, and is currently being studied as a method to assess migration readiness, hypoosmoregulatory capability, and potential for ocean survival of hatchery produced anadromous fishes. In coho salmon, for example, ATPase activity in fresh water normally begins to increase in late April, peaks in late May, and then begins to decline, indicating that desmoltification is occurring. However, if the salmon are allowed to enter salt water, the gill ATPase activity continues to increase for an additional 30 days finally reaching a level three to four times that in fresh water; indicating that full osmoregulatory capability has been reached. Larger smolts do not necessarily have the highest gill ATPase activities but, at least for spring chinook salmon, there apparently is a minimum fish size which must be attained before parr can enter the gill ATPase cycle (Ewing et al., in press). For spring chinook salmon, this minimum fish size is approximately 80-90 mm (Fig. 4).

ATPase development representative of what can be expected during

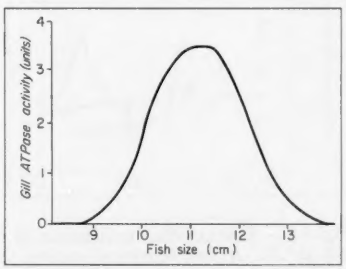

Figure 4.—The influence of fish size on changes in gill Na^+, K^+-ATPase activity, spring chinook salmon. Critical size is 8-9 cm (redrawn from Ewing et al., in press).

smolting of coho and spring chinook salmon and steelhead trout is shown in Figures 1, 2, 3, and 4. However, several fish cultural, environmental, and physiological factors must be taken into account when ATPase monitoring results are used to develop time, age, and size at release strategies for salmon enhancement programs. First, the length of the out-migration path should be considered in interpreting the data when low gill enzyme activities are obtained at the hatchery. That is, smolts with several hundred miles of downstream migration to accomplish may develop maximally elevated ATPase activity in the river rather than in the hatchery (Bjorn et al., 1978). In addition, recovery from adverse hatchery practices may occur in the river, or the act of migration itself may stimulate activity (Fig. 5). Second, certain salmonid races may have inherently lower ATPase enzyme levels than others. Finally, as mentioned earlier, crowding, pre-release disease treatments, or low-level contaminant exposure during rearing may have partially or completely inactivated the ATPase system. Significantly, this phenomenon can also be used in a positive way, as a sensitive method of biological monitoring for environmental quality.

Seawater Challenge Tests

Seawater tolerance, or ability to survive for 30 days in seawater, has long been used as a measure of smolting success (Conte and Wagner, 1965). However, as discussed earlier, this criterion fails to distinguish between large parr and true smolts in many salmonid species. For example, nonsmolting races of trout can thrive in seawater, provided that they are of sufficient size (Landless and Jackson, 1976). Also, recent aquacultural experience has shown that incompletely smolted coho salmon can survive in seawater, seemingly normally, for several months before they begin to show retarded growth (Mahnken, 1973; Kennedy et al., 1976; Clarke and Nagahama, 1977). Recently, Komourdjian et al. (1976a) and Saunders and Henderson (1978) showed that challenge with high (40‰) salinity is a good test to reveal any undeveloped salinity tolerance in Atlantic salmon and is therefore an excellent indicator of smolt status and capacity for hypoosmoregulation.

Challenge with 30‰ seawater is more common and is also an effective test of smolting if adaptation is assessed by determining the plasma sodium concentration that occurs after 24 hours (Clarke and Blackburn, 1977). True smolts suffer only a mild hypernatremia and can regulate plasma Na^+ to initial levels after abrupt transfer to seawater, as compared with the severe hypernatremia occurring in parr or postsmolts which have undergone desmoltification in fresh water (Parry, 1960; Houston, 1960, 1961; Koch, 1968; Clarke and Blackburn, 1977). This test can be run simply by taking a 10-fish blood sample for plasma sodium analyses 24 hours following transfer to seawater at their acclimation temperature (Clarke and Blackburn, 1977). Alternatively, following the plasma Na^+ profile over a 4-day period can furnish useful information.

Experience with accelerated under-yearling coho salmon indicates that a plasma sodium concentration of less than 170 meq/liter after 24 hours in seawater is predictive of long term ability to grow and develop normally in the ocean. Test results obtained from wild and hatchery reared yearling coho salmon stocks of coastal British Columbia suggest that the optimal performance range for smolts is actually in the area of 150-160 meq/liter (Clarke and Blackburn, 1978). However, other stocks, such as Columbia River salmon, may not perform as well as this. In addition, it must be emphasized that the indicated performance range values will only be obtained during the first 24-48 hours in seawater, since osmoregulatory homeostasis will eventually develop even in parr, if they survive.

For example, Saunders and Henderson (1970) found that plasma chloride and osmolality were similar 3 weeks after transfer to seawater in Atlantic salmon which were smolted, and in those subjected to an unnatural photoperiod regime which had disturbed the smolting process. However, normal growth cannot be maintained, possibly because the energy costs of hypoosmoregulation in non-functional or poorly functional smolts are excessive (Woo et al., 1978). Thus, stunted coho salmon survive for several months in seawater net pens and are able to regulate their plasma sodium concentrations into the normal range but suffer poor growth, parr-reversion, and eventual mortality (Clarke and Nagahama, 1977).

Apart from coho salmon, the seawater challenge blood sodium test has been used as an indicator of smolt condition and probable ocean survival of chinook and sockeye salmon and

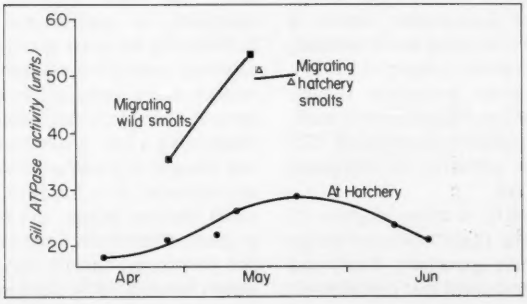

Figure 5.—Gill Na^+, K^+-ATPase activity of hatchery and wild Columbia River steelhead trout smolts. Migration itself may stimulate ATPase development to the level found in migrating wild smolts (redrawn from Bjorn et al., 1978).

steelhead trout. The degree of hypernatremia that results in smolts that are fully functional appears to be similar in all four anadromous species (Clarke and Blackburn, unpubl. data). In the case of fall chinook salmon, however, certain races may normally enter estuaries before the smolting process is fully complete (Clarke and Blackburn, 1978).

Thyroxine (T_4) Monitoring

As mentioned, there is also a substantial thyroid surge during smoltification and the monitoring of plasma T_4 holds considerable promise as an alternative method of tracking smolt development during rearing and for predicting likelihood of ocean survival (Dickhoff et al., 1978). As illustrated in Figure 6, T_4 levels in freshwater show a markedly sharper increase and decline profile than does ATPase activity, but high plasma T_4 concentrations are not sustained during saltwater residence.

Physiological Problems During Release and Emigration

Following hatchery rearing and release, downstream migrant smolts must again physiologically cope with a variety of environmental stress factors in the rivers and estuaries before their entrance into the sea. These include: dam passage problems, unfavorable stream flows and temperatures, predators, air supersaturation, activation of their own latent infections due to environmental stress, interference with saltwater adaptation in the estuary because of gill infestations by *Costia*, and, where trucking and barging around dams is employed, handling stress and descaling.

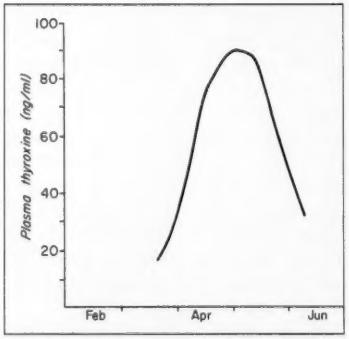

Figure 6.—Plasma thyroxine concentrations during smoltification of coho salmon (redrawn from Dickhoff et al., 1978).

The mortality pattern during emigration caused by dam passage, unfavorable temperatures and stream flows, gas supersaturation, and predation are fairly well recognized. However, many other physiological problems such as those caused by 1) scale loss, 2) the activation of latent, or subclinical, infections due to the stress of seawater conversion, or 3) effects of gill parasite infestations, have received less attention, and are briefly reviewed here.

Environmental Stress and Scale Loss

Because of the major smolt mortality problem caused by dam passage, gas supersaturation in rivers, predation, and unfavorable temperatures, smolt hauling operations are in progress in rivers such as the Columbia. However, reduced survival due to handling stress, scale loss, and subsequent disease problems have led to the necessity for stress mitigation procedures (Long et al., 1977). Mineral salt additions of several kinds are known to be useful in minimizing handling stress in general. These include NaCl at 3-5‰ (Wedemeyer, 1972; Hattingh et al., 1974) or $CaCl_2$ at 50 mg/liter (Wedemeyer and Wood, 1974). For smolt hauling, salt (NaCl) at up to 15‰ has found considerable use both for stress mitigation and for *Saprolegnia* control, a major cause of delayed smolt mortality if scale loss occurs (Long et al., 1977). Normally, some potassium is also added if NaCl at 10‰ or more is used. In addition, diluted seawater (5-15‰) can also be effective in mitigating handling stress.

Unfortunately, various degrees of scale loss are fairly common during smolt transport operations. Bouck and Smith (1979) showed that considerable 10-day seawater mortality occurred when smolts were experimentally descaled as little as 10 percent of the body surface. The estimated 10-day TL_m was 50 percent mortality for a 10 percent scale loss on the ventral surface. These results have serious implications for the evaluation of smolt hauling programs involving stocking into seawater or of high seas tagging results, because of the delayed aspect of the mortality pattern. However, for smolt hauling involving release into rivers, the consequences would potentially be lessened by the fact that a 5-day recovery period in fresh water almost completely restored full tolerance to seawater, as judged by lack of mortality. However, partially descaled smolts released near a river mouth would probably show an avoidance reaction to salinity and would tend to remain in the estuarine area longer than normal, thus being exposed to disease and predation. Another physiological consequence of scale loss to consider is that potentially lethal amounts of Mg^{++} and K^{+} can then be absorbed from seawater or from the stress mitigating salt mixtures (Wedemeyer, unpubl. data). As little as 10 percent dorsal scale loss can result in a life-threatening hyperkalemia and hypermagnesemia in coho salmon smolts. Even if immediate mortalities do not occur, blood electrolyte imbalances of this magnitude are debilitating and would be expected to considerably reduce the ability of a smolt to survive further stress, or escape predation.

Activation of Latent Infections

There is consensus among fish disease specialists, but little published data, that latent bacterial or viral infections in smolts are probably activated by the stress of migration and saltwater adaptation resulting in substantial ocean mortality. In one documented example, coho salmon smolts undergoing a low grade bacterial kidney disease (*Corynebacterium salmonis*) epizootic at a hatchery, were divided into two groups, one transferred to another freshwater pond and the second transferred directly into 28‰ saltwater (Sanders, 1979; Sanders et al., in press). The results are summarized in Figure 7. As seen, the epizootic was exacerbated and kidney disease mortality increased dramatically in the group

transferred into saltwater. These, and other case history results strongly suggest that smolts released with even subclinical infections are likely to have the disease activated by the stress of migration and conversion to saltwater and will suffer a delayed mortality in the ocean. In the experiment reported here, the majority of kidney disease deaths occurred 2 to 4 months after the fish entered saltwater. Frantsi et al. (1975) reported that bacterial kidney disease infected Atlantic salmon are generally unable to survive acclimation to seawater and suggested that few infected smolts survive to return as adults.

In the case of marine fish diseases, the recently discovered viral erythrocytic necrosis could potentially account for a portion of the so-called "natural" ocean mortality of anadromous fishes. Since it is a stress mediated disease, apparently contracted in estuaries, the prevention of estuarine habitat alteration offers a potential means of control. This would be especially promising for species such as chum, *O. keta,* pink, *O. gorbuscha,* or chinook salmon whose life histories include a significant amount of estuarine residence.

Gill Parasite Infestations and Seawater Tolerance

Experience gained by the Washington Department of Fisheries[4] suggests that only 15-30 *Costia necatrix* per gill arch will result in poor survival when hatchery coho and chinook salmon smolts reach seawater. This is presumably due to physical damage to gill chloride cells which results in reduced osmoregulatory competence.

Summary and Recommendations

On the basis of our present understanding and appreciation of the coordinated physiological processes called smoltification, several guidelines to be followed or precautions to be observed during the winter and spring preceeding hatchery smolt release can be recommended.

1) Temperature should follow a natural seasonal pattern. If elevated temperatures are used to promote growth, this is best done during October through December. Temperature should not be elevated too quickly or to more than about 10°C in late winter unless accelerated smolting is desired. Temperature should be held below 13°C at least 60 days prior to release of Atlantic salmon and steelhead trout. Similarly, for coho and chinook salmon, water temperatures should be held below about 12°C, if possible, in order to prevent premature smolting and desmoltification. For some anadromous fish, the temperature regimens needed to produce the most successful smolts are unknown.

2) In the absence of complicating factors such as altered river and estuarine ecology, smolt releases should be timed to coincide as nearly as possible with the historical seaward migration of naturally produced fish in the recipient stream, if genetic strains are similar. At headwater production sites, much earlier release may be called for. Planting large parr in the fall would not be unreasonable if observation shows naturally produced parr move to downriver sites at that time. The desired result is that hatchery reared smolts which are genetically similar to wild smolts enter the sea at or near the same time.

3) Proper photoperiod regulation is probably the most important environmental consideration to assure production of functional smolts. Although the facilities needed for photoperiod control are minimal, this environmental priming factor should be altered with caution, since it is easily misused with disastrous results. Unless accelerated or delayed smolting is required, the best procedure is to hold the presmolts in outdoor ponds with no artificial light. This may preclude the use of night floodlighting often needed for hatchery security. Indoor rearing should also be done under natural light if possible. Otherwise, artificial lighting should be

[4]Richard L. Westgard, Fish Pathologist, Washington State Department of Fisheries, Olympia, Wash., pers. commun. April 1979.

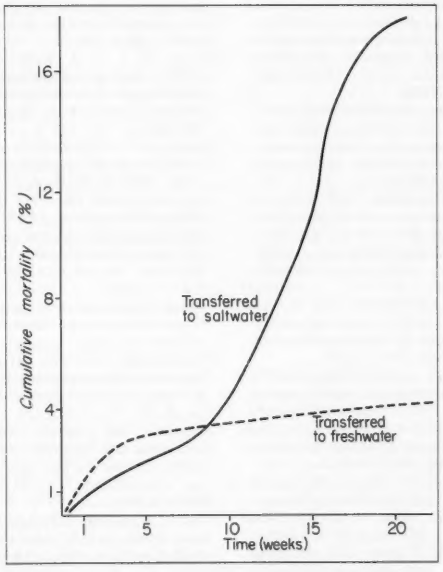

Figure 7.—Effect of transfer to saltwater on mortality from enzootic bacterial kidney disease in juvenile coho salmon (Sanders, 1979).

timed to simulate natural intensity and photoperiod.

4) Smolts must not be sent to sea with latent infections or gill parasite infestations. Ideally, pre-release disease treatments should be limited to medication known to have no effect on smolt performance. When this is not possible, an appropriate freshwater recovery period must be allowed.

5) In attempts to alter time, age, and size at release to fit resource management requirements, physiological testing for osmoregulatory competence should be used to track smolt development and monitor effects of hatchery practices and environmental factors. Gill Na^+, K^+-ATPase, plasma thyroxine (T_4), or the seawater challenge-blood sodium test are recommended.

6) Finally, in evaluating smoltification indices and hatchery performance, the major criterion should be the summation of hatchery returns and contribution to the fishery.

Acknowledgments

Many of our professional colleagues contributed judgements on technical interpretation during the preparation of this review. We especially thank H. Lorz and R. Ewing, Oregon Fish and Game Commission; R. Brett and T. Bilton, Department of Fisheries and Oceans, Canada; L. Folmar, C. Mahnken, and W. Zaugg, National Marine Fisheries Service.

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The Efficiency of Mollies, *Poecilia mexicana*, as Live Bait for Pole-and-Line Skipjack Fishing: Fishing Trials in the Tropical Central Pacific

PATRICK G. BRYAN

Introduction

It is generally agreed that limited bait supplies prevent further expansion of skipjack tuna, *Katsuwonus pelamis*, pole-and-line fisheries in the central and western tropical Pacific. A tuna baitfish workshop was held in Honolulu in 1974 to address this problem and bring together current knowledge (Shomura, 1977). The recommendations concerning cultured baitfish species called for further field tests and for evaluation of species suitability for pole-and-line tuna fishing. This study tested the desirability of the cultured mollie, *Poecilia mexicana* (Pisces: Poeciliidae), in pole-and-line tuna fishing aboard a modern, well equipped Japanese live-bait vessel.

Poecilia mexicana was tried as live bait in several preliminary trials around American Samoa in 1974 and 1975 and results indicated that this species was a suitable baitfish for skipjack tuna (Baldwin, 1977b). The Office of Marine Resources, American Samoa Government, pursued the culture of this species. More extensive sea trials using cultured *P. mexicana* were conducted in American Samoa and Fiji in January, February, and March 1978 aboard a modern well equipped west coast live-bait vessel, *J-Ann* (Vergne et al., 1978).

In Hawaii, other potential alternate live baits have been tried, e.g., tilapia, *Tilapia mossambica*, (Shomura, 1964) and threadfin shad, *Dorosoma petenense*, (Iverson, 1971), but the shad tests proved inconclusive. Although tilapia showed promise, further interest and subsequent funding for the project has waned.

June and Reintjes (1953) provided a practical field guide to the baitfishes of the central Pacific and Baldwin (1977a) gave an excellent review of baitfish literature. In this report, skipjack tuna refers to *Katsuwonus pelamis* and yellowfin tuna refers to *Thunnus albacares*, as given by Klawe (1977).

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ABSTRACT—*Cultured mollies,* Poecilia mexicana, *were tested as live bait for pole-and-line skipjack tuna,* Katsuwonus pelamis, *fishing. Fishing trials were conducted in American Samoa, Tuvalu, and the Gilbert Islands in June and July 1978. Fishing in American Samoa was poor. Overall, 80 schools were chummed and 3,151 tuna (mostly skipjack) were tagged, including 1,018 in 1 day on mollies alone around Funafuti. The ratio of mollies chummed to tuna tagged was 1:17; under a commercial effort, a ratio of 1:59 could have been expected. Mollies performed as well as or better than wild bait* Spratelloides delicatulus. *Small mollies seemed to work as well as larger ones. The mollies were cured of bacterial infections by treating them in the baitwells with an antibiotic. After 2 weeks aboard the vessel, the remaining mollies weakened and began dying; they had been fed on tuna fish meal and dietary defiency is the suspected cause. Because mollies tend to crowd in the neck of the baitwells, modification of baitwells warrants consideration in future work. Lures designed to simulate mollies may also be important.*

Materials and Methods

Mollies used in the fishing trials were cultured and reared in enclosures located at Pago Pago International Airport in American Samoa (Fig. 1). The enclosures were constructed by staking and fencing with synthetic plastic screen material having a mesh size of approximately 1.5 mm. The mollies were seined from the enclosures and placed in 2,300-l capacity fiber glass tanks (described by Iverson and Puffinburger, 1977) at a density of about 25 mollies (37 g) per liter of brackish seawater (25 ‰). A water soluble antibiotic (Furacin[1], Eaton Laboratories) was mixed in at a ratio of 0.1 g/l of water as a prophylatic. Oxygen was provided through two large airstones in each tank according to methods described by Baldwin (1970). Dissolved oxygen in each tank was kept at levels above 6 ppm by this system.

The two holding tanks were mounted on a flatbed truck with the oxygen system and the fish were transported to Pago Pago Harbor about 15 km from the culture site (about 35 minutes). Upon arrival, the fish were gravity fed from the transport tanks down an enclosed plywood chute into one of two floating receivers (holding pens). One receiver measured 6.5×6.5×2 m in depth, the other was 3×3×2 m in depth. Both receivers were constructed of wood and had working platforms around the perimeters. They were floated by means of 220-l (55-gallon)

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

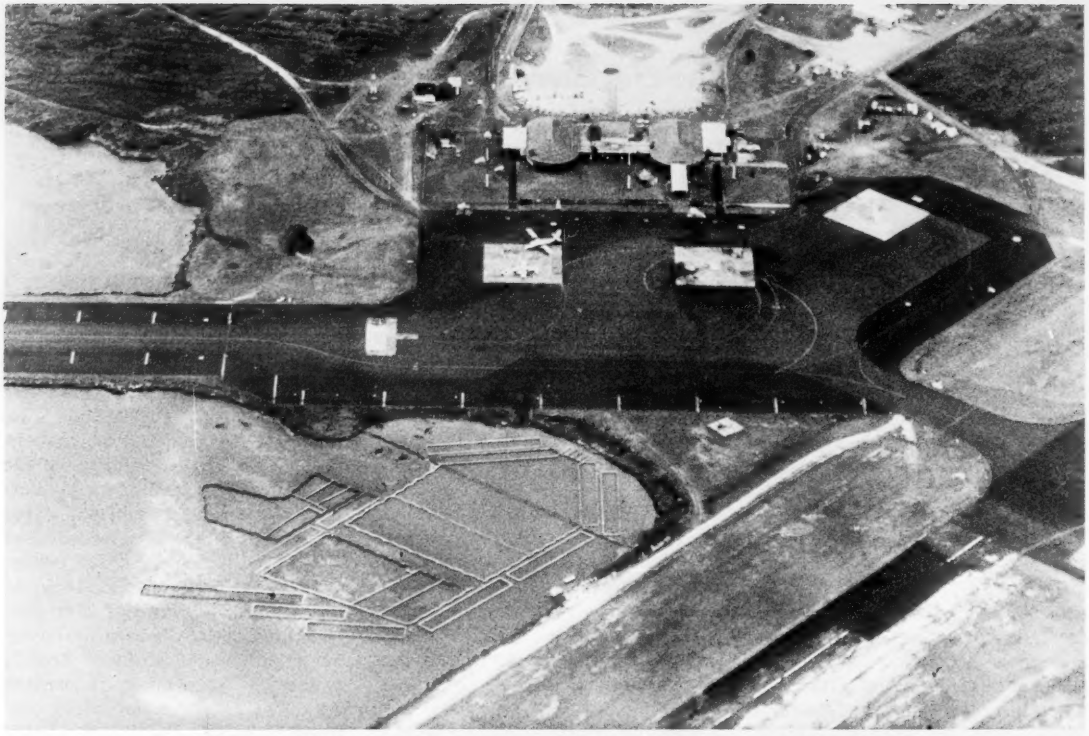

Figure 1.—Aerial view of mollie culture complex (bottom half of photograph).

oil drums. Each receiver consisted of an outer bottom section made of 6-mm galvanized screen which protected an inner prefabricated nylon net of 4-mm mesh size.

To load the baitfish into the baitwells, the receivers were brought alongside the vessel and the baitfish transferred with buckets. Approximately 373,000 mollies (507 kg) were loaded aboard the *Hatsutori Maru* on 16 June and another 134,000 (202 kg) were loaded on 21 June (total, 710 kg). Two size groups were represented: Baitwell No. 1 contained about 66,000 (46 kg) smaller mollies ($\bar{x}$ SL = 27.0 mm; $\bar{x}$ WT = 0.7 g)[2]. The other four wells contained about 442,000 (663 kg) larger mollies ($\bar{x}$ = 36.2 mm; $\bar{x}$ WT = 1.5 g).

[2]SL =standard length; WT =weight.

Figure 2.—Japanese live bait pole-and-line fishing vessel, *Hatsutori Maru*. Name on vessel is misspelled.

The vessel used for the fishing trials was a Japanese sampan, *Hatsutori Maru* (Fig. 2). At the time of the trials, it was under charter to the South Pacific Commission (SPC) for a 3-year period to conduct a skipjack tagging program throughout the Pacific basin. Through mutual agreement between SPC and American Samoa Government, these tests were incorporated into her planned schedule. The crew consisted of nine Japanese (including the captain)

and nine Fijians. In addition three SPC scientists and the author were aboard during these fishing trials. The vessel specifications are as follows: Launched, 12 November 1967; gross tonnage (metric), 192; length overall, 42 m; registered length, 34 m; beam, 6.7 m; draught, 3.2 m; speed, 11.8 knots max.; range, 6,000 miles. Detailed specifications and the vessel layout are given by Kearney and Lewis (1978). The bait tank (baitwell) capacities beginning from the bow are: No. 1, 13.9 m^3; No. 2, 14.0 m^3; No. 3, 13.7 m^3; No. 4, 16.8 m^3; and No. 5, 16.1 m^3. Each well is pumped independently of the others and all have open seawater circulation. The vessel is also equipped with a saltwater spray system with individual adjustable nozzles located at intervals (about 0.5 m apart along the gunwales) around the stern, the bow, and along the entire length of the port side (Fig. 3). The fishermen used fiber glass fishing poles with mono filament lines and leaders. The lures were the traditional squids with chrome heads and white (or white and red) feathers partially skirted with processed cat's (feline) skin. Most fishermen used a #2.3 lure (Japanese numbering system) for the smaller tuna and a #2.5 for the larger tuna.

Night baiting for wild baitfishes was done using two submerged lights (each 1 kW), one hung off the port side near the bow and the other hung from a skiff containing a diesel powered generator and positioned about 100 m behind the stern of the vessel. The bait was captured by a Japanese style stick held lift net (bōuke ami) pulled in from the starboard side of the vessel. An illustrated account of the Japanese night baiting method is given in the JAMARC report (Anonymous, 1976).

There are two chumming stations on board the *Hatsutori Maru*; one tank (station) is located on the port bow and the other on the port stern. Bait was transferred from the baitwells to the chumming tanks in buckets as needed. Usually, chumming commenced from both stations as the vessel approached a school of tuna. When the fish were observed to break at the surface along the "chum line," the vessel was slowed to a stop while making a half circle so that the port side was positioned at more or less a right angle to the "chum line." The water spray system was then turned on as the tuna approached the vessel and fishing commenced.

Figure 3.—Spray system along the port gunwales of the *Hatsutori Maru*. Chummer has just thrown some live mollies.

On those occasions when wild bait was available, it would be chummed from the bow (or stern) while mollies were stimultaneously chummed from the stern (or bow). On the following day, the order would be reversed, and so forth. Fish caught on the stern were kept separated from those caught on the bow and amidships.

Buckets of mollies loaded aboard the vessel were periodically sampled and weighed to provide estimates of weight and numbers chummed. When night baiting for wild bait, random buckets were sampled and weighed and the species composition recorded. In addition, dead bait from each well was collected and weighed every 6 hours to estimate mortality. In rough seas, however, this proved difficult because many of the dead baitfish would be washed overboard before they could be collected. Bait transferred from the baitwells to the chumming tanks were recorded in numbers of buckets, each bucket containing an average of 3.0 kg of fish.

Results

Mollies as Baitfish

The mollies used in these trials were exposed to considerable stress and rough handling from the initial seining, transporting, and loading into the baitwells on 16 or 21 June in American Samoa. On 22 June a large percentage of the mollies in baitwells 1, 2, 3, and 4 aboard the *Hatsutori Maru* were apparently infected by a bacterial pathogen and possibly fungus. Each of these wells was treated with a water soluble antibiotic (Furacin water mix) by adding about 0.1 g antibiotic per liter of water and turning off the pumps for about 40 minutes. The same treatment was repeated the following day and no further disease problems were encountered again.

Mollies which were regurgitated by tuna poled aboard the vessel often survived when they were picked up and placed back into a baitwell. Several times live mollies were removed from the stomachs of tuna and placed back into the baitwells where they swam away, apparently quite able to survive.

The mollies were fed dry tuna fish meal once or twice each day aboard the *Hatsutori Maru*. The constricting neck at the top of each well and the tendency

of the mollies to crowd at the sufrace when being fed made efficient feeding difficult. If the food was spread on the surface, it was instantly consumed by the fish nearest to the surface. When the fish meal was made into a wet mash and sunk, the fish still would crowd together in the neck of the well attempting to reach the surface.

The baitwells on the *Hatsutori Maru* are designed for alternate use as reefer holds to freeze tuna and subsequently the walls of the wells are lined with freezer coils. To remove the bait from the wells, a stick-held crowder net was used to concentrate tne fish at the surface where they were more accessible. Once the crowder was initially used, the mollies tended to avoid it by swimming downward and hiding between the coils and in the corners of the wells. This made it ultimately necessary to drain the baitwell and scoop the remaining mollies (about 30 percent) out by hand. Similar problems were encountered on the *J-Ann* even though the *J-Ann's* baitwells were not lined with coils but had smooth interiors.

For the most part, fishing was conducted with the vessel stopped and the behavior of the mollies when chummed facilitated this method of fishing. The mollies would initially remain motionless for several seconds upon hitting the water, then swim either singly or in small groups back underneath the water spray and alongside the hull of the vessel. This usually brought the tuna close in under the spray in reach of the lures. Often after fishing a school for several minutes the biting would slow down considerably. When this happened, the captain would ease the vessel ahead briefly, flushing out the mollies close to the hull. The maneuver usually initiated a renewed feeding response and subsequent vigorous biting. This method was often repeated several times while fishing a school and proved to be quite effective to renew the biting response.

When pursued or attacked by tuna, the mollies would often repeatedly jump from the water, sometimes somersaulting through the air. At no time were the mollies observed to dive. Sometimes small aggregations of mollies would venture 1-2 m from the vessel but would always return, particularly when being chased by feeding tuna. One night while the *Hatsutori Maru* was drifting, I scooped over a bucket of mollies back aboard the vessel. The mollies were apparently attracted by the vessel's lights and remained alongside after having been chummed several hours earlier while fishing a "sundown school."

Several schools were chummed with small mollies ($\bar{x}$ SL = 27.0 mm; $\bar{x}$ WT = 0.7 g) than those normally used ($\bar{x}$ SL = 36.2 mm; $\bar{x}$ WT = 1.5 g). No distinguishable differences in the behavior of these two size groups or their respective catchability were detected. Several other schools were chummed with a mixture of these two size groups and again no differences were noted.

I covered the chrome and skirt of several squids of different sizes with dried dark skin of mahimahi and fished these lures next to the traditional lures on several occasions. In two schools, the dark colored lures received more strikes than the stock lures. In other schools the modified lures performed as well as or better than the traditional lures.

Survival of Mollies

Of the 710 kg of mollies loaded aboard the *Hatsutori Maru*, about 506 kg (includes 27 kg mixed with sprat) were chummed (Table 3) and about 203 kg were lost to mortality or otherwise, i.e., human error, pump failure, and overflows. Most of the mortality occurred after 2 July. Total mortality through 1 July was 7 percent ($\bar{x}$ daily mortality, 0.44 percent). From 2 July through 5 July mortality increased significantly and about 71 percent of the remaining mollies (215 kg) were lost.

On 2 July, the pump to well No. 3 was accidentally turned off for an undetermined time causing the mollies to crowd at the surface in the neck of the well (in distress, mollies come to the surface and gulp air). The dissolved oxygen was apparently depleted and the mollies began dying. After the problem was remedied, the mollies appeared weak and lethargic, crowding in the neck of the well. During the night the mollies plugged the outlet manifold causing the baitwell to overflow.

The following day (3 July) mortality continued in this well and the mollies in well No. 1 began showing similar symptoms, crowding at the surface in the neck of the well. High mortality subsequently began in this well also and this condition continued in both wells until all the bait was used during chumming just before dark on 5 July. Even in their weakened state, the mollies were very effective as baitfish. I examined 10 dying fish from each well and found one symptom in common; all had enlarged gall bladders full of dark green fluid. Externally the fish appeared healthy and normal, certainly not emaciated.

General Fishing Results

Table 1 provides a daily summary of schools chummed and/or fished ("fished" indicates that fish were caught from the school). Overall, 80 schools were chummed and 30 schools were fished (38 percent). The average size of skipjack tuna caught was 2.9 kg; for yellowfin tuna the average size was 1.8 kg. A grand total of 11,210 kg (95.5 percent) of skipjack tuna and 505 kg of yellowfin tuna was caught. Of 4,187 tuna caught, 3,151 were tagged and released. Most of the other fish encountered were rainbow runner, *Elagatis bipinnulata*, and though these schools were never fished for more than a few minutes, they usually came quickly to the vessel and were easily caught. Only several mahimahi, *Coryphaena hippurus*, were caught, these trolled. Although the major goal of this cruise was to tag tunas, these trials were considerably more successful than those undertaken by the *J-Ann* (Vergne et al., 1978) as shown in Table 2.

Table 3 gives the fishing results according to the type of bait used. On 5 days, both mollies and captured wild bait (round herring or sprat, *Spratelloides delicatulus*)[3] were chummed (sprat from the bow simultaneously with mollies from the stern and vice

[3]The Hawaiian name is "piha."

versa on alternating days). Twenty-one schools were chummed in this fashion and nine were fished (43 percent). More tuna were tagged on mollies than on sprat in five schools and more tuna were tagged on sprat than on mollies in four schools. From the nine schools, 515 tuna (1,329 kg) were tagged on mollies versus 386 (858 kg) tagged on sprat.

Most schools took longer to follow the chum line to the boat than was previously experienced by the *Hatsutori Maru* with schools chummed on wild bait in other island groups (J. P. Hallier, South Pacific Commission, Noumea. Personal communication during these trials). Usually it took 30-60 seconds from the time the school first broke the surface on the chum line until the school reached the stern of the vessel and could be fished. This was true even when both mollies and sprat were chummed.

Stomach analyses were performed on decked tuna taken from almost every school fished (Table 4). Poled skipjack tuna and yellowfin tuna frequently regurgitated mollies as they were pulled aboard. The stomachs of most tuna examined contained mollies (RF, 78 percent)[4] (Fig. 4). The stomach of one large skipjack tuna contained 133 (200 g) mollies. Most fish examined from schools chummed with *S. delicatulus* contained the same (RF, 63 percent).

Almost all schools were located by the presence of birds (schooling terminology used here adapted from Scott, 1969). Schools encountered 20 km or more from land tended to be fast moving breezers accompanied by high flying birds; often the birds would disperse when a school was chased down. Schools encountered less than 20 km offshore tended to be jumpers or foamers, slower moving, and accompanied by greater numbers of birds than offshore schools. The stomachs of inshore fish usually contained more food items and more biomass (other than chum) than stomachs examined from offshore fish. In general, offshore schools bit better than inshore schools.

[4]RF =relative frequency.

Table 1.—Daily summary of fishing results by *Hatsutori Maru*.

Date	Locality	Bait	No. schools chummed	No. schools fished	Kg bait chummed	Kg tuna tagged[1]	Kg bait: Kg tuna
June 17	American Samoa	Mollies	7	0	33	0	
June 18	American Samoa	Mollies	5	0	24	0	
June 19	American Samoa	Mollies mixed with *Spratelloides gracilis*	1	1	27	165	1:6
		Mollies	4	1	39	58	1:1
June 21	American Samoa	Mollies			3	0	
		Stolephorus devisi	1	0			
					9	0	
June 25	Nearing Funafuti	Mollies	8	6	125	2,518	1:20
June 26	Funafuti	Mollies	3	2	24	299	1:12
June 27	Funafuti	Mollies	13	4	57	1,672	1:30
June 28	Funafuti	Mollies	5	1	15	118	1:8
June 29	Funafuti & Nukufetau	Mollies			18	84	1:5
	Nukufetau	*Spratelloids delicatulus*	7	4	30	124	1:4
June 30	Nukufetau & Funafuti	Mollies			12	25	1:2
		S. delicatulus	4	1	21	70	1:3
July 1	Funafuti	Mollies					
		S. delicatulus[2]	1	1	15	164	1:11
					18	192	1:11
		Mollies	6	2	51	1,617	1:32
July 2	Funafuti	Mollies	6	4	21	302	1:14
July 4	Steaming toward Tarawa	Mollies			12	314	1:26
		S. delicatulus	4	1	24	118	1:5
July 5	Between Tarawa & Onotoa	Mollies			30	742	1:25
		S. delicatulus	5	2	39	354	1:9

[1]Includes both skipjack tuna and yellowfin tuna.
[2]Depleted *S. delicatulus* in first school.

Figure 5 shows the general course of the *Hatsutori Maru*.

American Somoa Fishing Results

Five days were spent fishing and baiting (Table 5) around American Samoa where generally fishing was very poor. High winds (20-30 knots) and heavy seas made spotting of birds difficult. The surface water temperature averaged 28.0°C. Eighteen schools were chummed but only three were fished (17 percent). One of the fished schools was chummed with a mixture of mollies and round herrings (*S. gracilis*). Although 80 buckets (120 kg) of the anchovy *Stolephorus devisi* were captured by night baiting in Pago Pago Harbor during the early morning of 21 June (Table 5), only one school of tuna was spotted that day and it did not respond to chumming by either mollies or anchovies. Most schools would not even bite trolled lures and several schools followed along with the vessel for several minutes, ignoring the trolled lures. Overall, only 74 (223 kg) tuna were tagged in American Samoa waters (Kearney and Hallier, 1978).

Table 2.—Comparison of fishing results using mollies between the west coast vessel *J-Ann* and the Japanese vessel *Hatsutori Maru*.

Vessel	Kg mollies chummed	Kg tuna caught	Kg mollies: Kg tuna
J-Ann[1]	1,834	[3]17,542	1:10
Hatsutori Maru[2]	479	[4]10,236	1:21

[1]Commercial fishing effort, 6 January-14 March 1978.
[2]Tagging effort only, 17 June-5 July 1978.
[3]Includes trolled fish.
[4]Does not include trolled fish.

Table 3.—Fishing results by *Hatsutori Maru* according to type of bait used.

Type of bait	No. schools chummed	Kg bait	Kg tuna[1]	Kg bait: Kg tuna
Mollies	80	479	7,913	1:17
Spratelloides delicatulus	21	132	858	1:7
Mollies *Spratelloides gracilis* mixture	1	27	165	1:6

[1]Based on tagged fish only.

Table 4.—Food items found in stomachs of tuna examined from 23 schools. Data presented were randomly subsampled from larger stomach analyses samples to facilitate conciseness.

School No.	Tuna	Number of food items in stomach					
		Mollies	Sprat	Other fish	Squid	Shrimp	Other crustaceans
3	Skipjack	65	18				
	Skipjack	37	6				
16	Skipjack	7		2			
	Skipjack	20					
19	Skipjack						
	Skipjack	13					
20	Skipjack	10					
	Yellowfin	15				P[1]	
21	Skipjack						
	Yellowfin	8					P
22	Skipjack	3					
	Skipjack	4					
23	Skipjack	3		P			
	Skipjack	7					P
24	Skipjack					1	P
	Skipjack						
29	Skipjack			4			1
	Yellowfin	2		P			P
42	Skipjack	1					
	Yellowfin	7		1		TNC[2]	P
45	Skipjack	4					
	Yellowfin	41			1		P
52	Skipjack						P
	Yellowfin				1		1
53	Skipjack	7	1				
	Yellowfin						2
54	Skipjack						
	Skipjack	19	25	P			
58	Skipjack	8	17			TNC	2
	Skipjack					TNC	1
59	Skipjack	53	55	P	1		
	Skipjack	38	31	1	1		
61	Skipjack	28		P			2
	Skipjack	2		1			
65	Skipjack	50		2	2	TNC	1
	Skipjack	13				TNC	1
68	Skipjack	4		P			
	Yellowfin	1		P	1		
70	Skipjack	4		2	P	TNC	1
	Skipjack	7		1	5		P
72	Skipjack	34	149	1	1		
	Skipjack	50	13				
78	Skipjack	5	14	1			1
	Skipjack	5	2	P			
80	Skipjack	49	2	5			
	Skipjack	21					

[1]P = present but not counted.
[2]TNC = too numerous to count.

Table 5.—Night baiting results by *Hatsutori Maru*.

Date	Locality	(No. buckets) and kg	Species	Composition
June				
18	American Samoa, Fagasa Bay	(1) 1.5	*Bregmaceros* sp.	0.95
			Pranesus pinguis	0.03
			Spratelloides delicatulus	0.02
19	American Samoa, Aoa Bay	(9) 14	*Spratelloides gracilis*	0.99
			Pranesus pinguis	0.01
21	American Samoa, Pago Pago Harbor	(80) 120	*Stolephorus devisi*	1.00
29	Tuvalu, Funafuti lagoon	(322) 483	*Spratelloides delicatulus*	0.92
			Bregmaceros sp.	0.07
			Pranesus pinguis	<0.01
			Archamia lineolata	<0.01
July				
3	Tuvalu, Funafuti lagoon	(386) 579	*Spratelloides delicatulus*	0.90
			Archamia lineolata	0.10
			Pranesus pinguis	<0.01

Tuvalu and the Gilbert Islands Fishing Results

On the evening of 21 June the *Hatsutori Maru* left Pago Pago heading north towards Funafuti (capital of Tuvalu, former Ellice Islands) for 2 days, and resumed fishing 25 June. The water temperature had increased to 29.0°+C and the wind velocity had reduced to 1-5 knots. A total of 1,018 (2,247 kg) skipjack tuna and yellowfin tuna were tagged on 25 June using mollies; eight schools were chummed and six were fished. We fished in the vicinity of Funafuti through 2 July and night baited twice in Funafuti lagoon, catching adequate quantities of sprat, *S. delicatulus* (Table 5). During the mornings and afternoons, most schools encountered around Funafuti and Nukufetau (an atoll north of Funafuti) were hesitant or slow to bite, whether being chummed with sprat or mollies. However, at about 1700 hours each day we encountered schools about 8 km offshore which bit very well until almost dark. Most of the fish tagged around the Funafuti area were caught from these "sundown schools" (Kearney et al., 1978).

On 3 July we left Funafuti lagoon, running all day towards the Gilbert Islands to the north. We resumed fishing on 4 July using the last of the remaining bait in a "sundown school" 5 July) Kearney and Gillett, 1978). The total number of tuna tagged in the vicinity of Tuvalu and the Gilberts was 3,077 (8,713 kg). Sixty-two schools were chummed and 28 were fished (45 percent).

Discussion

It is significant that during these trials the mollies performed as well as or better than the wild bait, *S. delicatulus*. The latter are considered an important baitfish in the Palau skipjack tuna fishery (Wilson, 1977), the Papua, New Guinea fishery (Smith, 1977), to a lesser extent in the Hawaiian skipjack fishery (Yoshida et al., 1977), and in other areas where they occur in reasonable abundance (Baldwin, 1977). Many Okinawan fishermen consider *S. gracilis* as being superior to anchovies

Figure 4.—Mollies cut from the stomachs of tuna poled aboard the *Hatsutori maru*. Each pile represents one stomach.

(Smith, 1977). Sprat are generally regarded as an excellent baitfish (Baldwin, 1977; Wilson, 1977; Smith, 1977), but fragile (Baldwin, 1977; Wilson, 1977). In this regard, we kept *S. delicatulus* alive for 3 days but mortality was high and increased with time.

The rate at which tuna schools approached the vessel was the same whether chumming with mollies alone or both mollies and sprat (one from the bow, the other from the stern or vice versa). Furthermore, gut analyses showed no significant preference for either the sprat or the mollies; the tuna seemed to feed equally on both when both baits were chummed. Mollies, then, are at least equally desirable to the tuna as sprat.

Much has been said regarding the desirable characteristics of a good baitfish (Hester, 1974; Smith, 1977; Yuen, 1977), and there appears to be disagreement about the size of a good baitfish. Smith (1977) reported a size of 60-80 mm as being desirable; Yuen (1977), on the other hand, recommended a size of 20-60 mm.

Size is an important factor in considering a cultured baitfish such as mollies. The faster the bait can be utilized, i.e., the smaller the size, the higher the production rates. Although the results of chumming with smaller mollies were not mentioned in the report by Vergne et al. (1978), there were no differences noted between the smaller mollies and

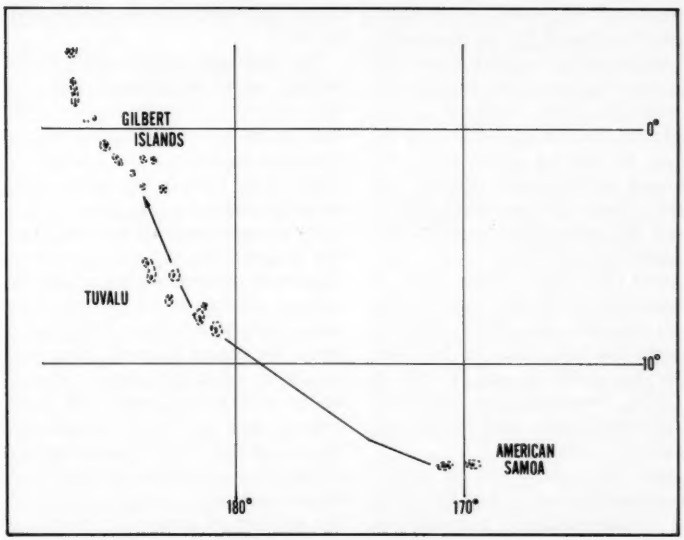

Figure 5.—Course taken by the *Hatsutori Maru* from American Samoa to Tuvalu and the Gilbert Islands.

the larger ones during either the *J-Ann* trials or the *Hatsutori Maru* trials. The smaller mollies tested aboard the *Hatsutori Maru* were around 27.0 mm SL, at the lower end of the range recommended by Yuen (1977) and much too small to be an attractive bait according to Smith (1977).

During the *J-Ann* trials, particularly around American Samoa, most skipjack tuna and yellowfin tuna caught were full of very small anchovies (probably *Stolephorus buccaneeri*) which were no more than 20 mm SL. Many of the tuna caught around Funafuti on this trip were full of small caridian shrimp with lengths about 10-15 mm TL. Optimum baitfish size may vary according to seasonal changes or with lunar cycles and is a subject calling for further studies.

Hester (1974) and Yuen (1977) gave durability as one of the characteristics of an effective tuna bait, although Smith (1977) simply assumed that a good bait is hardy anyway. Ikebe and Matsumoto (1938) stated that a baitfish should be selected for its desirability first and secondly for its hardiness, but this seems obscure. A bait must be able to withstand being captured, being transferred into the baitwells, and the trip to the fishing grounds. In the Hawaiian pole-and-line fishery, an annual average of 22 percent of all nehu caught die before they can be used (Yoshida et al., 1977).

During the *J-Ann* trials, balls of pelagic anchovy (*S. buccaneeri*) were twice captured and placed into the baitwells but both times the bait died before they could be used (Vergne et al., 1978). Hardiness, then, precludes attractiveness since dead bait is not considered usable.

Lewis (1977) examined the restrictions caused by weak bait on the Papua New Guinea skipjack pole-and-line fleet. He recommended more effort towards reducing mortality rates of bait species presently being utilized, thus freeing the fleet of the present day-to-day mode of operations.

Considering the above, perhaps the most important attribute of mollies is their hardiness. Few species of fish can be taken from the stomachs of their predators, placed into water, and swim away, especially after the predator has laid on deck for some time. Not only can mollies withstand handling many times over, but they can be easily cured of bacterial infections while in the baitwells by treating with antiobiotics, as was proven both on the *J-Ann* and the *Hatsutori Maru*.

The mortality problems we experienced the last several days aboard the *Hatsutori Maru* were probably the result of nutritional deficiencies since the mollies were fed straight tuna fish meal (50 percent protein). Mollies, being omnivorous, probably need other nutrients for long-term survival. Although they are fed with straight tuna fish meal in the rearing ponds, a variety of naturally occuring food items are available to them and they browse continuously. Mollies were held on the *J-Ann* for over 30 days with no such problems, but they were fed with a commercially prepared fish food (Trout Chow, Ralston Purina) as well as with fish meal.

The hardiness and durability of the mollies cannot be disputed, but their tendency to stay near the surface of the water in baitwells can lead to problems of oxygen depletion. Their tendency to crowd in the neck of the well is most noticeable when they are given food.

My observations indicate that olfaction triggers this surfacing response. Mollies are topfeeders in nature and the cultured stocks reared in American Samoa have been further conditioned to feed at the surface. Baitwell design will have to be taken into consideration if mollies are to be used; wells with larger surface areas should be considered. This would also allow for better feeding efficiency and lessen the problems now encountered with oxygen depletion. The addition of aeration or modification of the water circulation system may also prove valuable in alleviating these problems.

This report is based on tagging effort results only and not on a commercial fishing effort. Kearney (1978) assessed the fishing power of the *Hatsutori Maru* tagging operation relative to a commercial effort in Fijian waters. He found that when fishing commercially, the *Hatsutori Maru* could be expected to catch 3.47 times the catch of a tagging operation. Tables 1 and 3 are based only on tagged fish. If our tagged catch ratio (kg bait chummed:kg tuna tagged), 1:17, is multiplied by 3.47, then under a commercial effort the ratio could be expected to have been 1:59. If, in this tagging effort, we also include those fish dropped on deck during the tagging operation, the ratio is 1:21 (Table 2) and the corrected ratio expected for commercial fishing would be 1:73 (21 ×3.47).

The ratio of bait used to tuna caught in the Hawaiian commercial pole-and-line fishery is estimated to be about 1:29 (Yoshida et al., 1977)[5] and this fishery is based on the anchovy (nehu), *Stolephorus purpureus*, which is considered a superior live baitfish by Hawaiian fishermen. The breakeven price for a bucket of nehu (one bucket = 6.4 kg or 14.2 pounds, Hida and Whetherall, 1977) is $30.12 or $4.71/kg ($2.12/pound) (Crumley, 1977) and Wetherall (1977) calculated the average opportunity cost of nehu (1968-73) to be $67.88/bucket or $10.52/kg ($4.78/pound). Although Vergne et al., (1978) calculated the cost of producing 1 kg of mollies (*P. mexicana*) in American Samoa at about $26.40 ($12.00/pound), this cost analysis was based on a fiscal evaluation reflecting a highly experimental project designed only to produce as many mollies as possible to conduct sea trials, regardless of cost. Herrick (1977) has calculated cost projections on culturing a similar species, *P. vittata*, based on two levels of production: Production of 3,000 buckets (8,100 kg) per year (one bucket of mollies equals 2.7 kg) would cost $12.93/bucket; production of 30,000 buckets (81,000 kg) per year would cost $3.69/bucket ($1.37/kg). He further stresses that the ultimate economic feasibility of mollie

[5]The ratio was derived by applying Yoshida et al. (1977) annual average nehu mortality factor of 22 percent to all bait caught. Nehu makes up 95 percent of the bait catch in Hawaii.

culture enterprise will hinge upon their relative effectiveness as bait. The results of these trials clearly indicate that mollies are an effective baitfish and may even be more effective than some good wild baits used in the Pacific, e.g., *S. delicatulus*.

The results of the fishing trials conducted in American Samoa and Fiji by the *J-Ann* during January, February, and March 1978 (Vergne et al., 1978) were considerably lower than those obtained by the *Hatsutori Maru*, even though the latter represented a tagging effort. The *J-Ann* obtained a mollie live bait to tuna ratio of 1:10 while that of the *Hatsutori Maru* was 1:21 (Table 2). The *J-Ann* fished 30 percent of the schools chummed; the *Hatsutori Maru* fished 38 percent of the schools chummed.

While there were probably a number of reasons for the variation in the results of the two vessels, I feel the most important ones were: 1) The captain and crew of the *J-Ann* had had no previous fishing experience in the tropical central Pacific, 2) their gear was too heavy for skipjack fishing in clear tropical waters, and most important of all, 3) the vessel was not equipped with a water spray system.

The Japanese are the principal exploiters of tropical central and western and, to some extent, eastern Pacific skipjack tuna resources, harvesting two-thirds of the world's catch, mostly by live bait pole-and-line fishing (Yoshida et al., 1977). Their methods represent the state of the art for the pole-and-line fishery for a major portion of the tropical Pacific Ocean. The importance of the spray system in the pole-and-line skipjack tuna fishery is discussed by Yuen (1969) and Hester (1974).

Fishing around American Samoa was poor with June being recognized by local fishermen as part of the offseason. Not only do the skipjack tuna schools bite poorly (only 17 percent bit in these trials) but they move north during the austral winter. This agrees with other researchers (Uda and Tsukushi, 1934; Aikawa, 1937; Sasaki, 1939) who reported a seasonal difference in the response of skipjack tuna. Schools bit much better after we had run north for 2 days and reached warmer water. On this leg of the trip, 45 percent of the schools chummed bit.

Even though schools often would not bite in the morning or afternoon, the "sundown schools" often bit very well. Suehiro (1938) reported that morning was the best time for pole-and-line skipjack tuna fishing. In a study of the skipjack tuna response to live bait in the Hawaiian pole-and-line fishery, Yuen (1959) concluded that biting response was not affected by the time of day or weather conditions. These findings contrast greatly with our "sundown school" phenomena encountered around Funafuti. Suehiro (1938) also reported that offshore skipjack tuna schools responded better to pole-and-line fishing than schools close to shore and Yuen (1959) found that large skipjack tuna bit better the further away they were from land. In general, our results were similar to theirs, i.e., offshore schools usually bit better than inshore schools.

Often, when chumming with mollies, schools followed the chum line up to the stern of the vessel and fed actively on the mollies, but would not take the lures. Yuen (1969) believed that each skipjack tuna caught by pole-and-line represented an error in discrimination by the fish, i.e., the lure was mistaken for a live fish (chum). In a subsequent work, Yuen (1977) discussed how catch rates can be increased by causing the tuna to make mistakes and suggested that altering the lures to look more like the bait being chummed may increase the catch.

My observations were that the traditional chrome and white feathered squids are quite dissimilar in appearance and color to the mollies. This may have accounted for so many schools feeding on the chummed mollies but not taking the lures. The lures which I modified with dark mahimahi skin looked much more like a mollie than the stock lure. The fact that the modified lures worked as well as or better than the stock lures indicates that lure design is an important factor in the concept of using cultured mollies as live bait.

Hester (1974) stated that acceptability of a baitfish species must cover both mortality and effectiveness. These results show that mollies, *Poecilia mexicana*, are acceptable live bait for pole-and-line tuna fishing. Their hardiness will allow presently limited day fleets in many island groups to extend their range, giving them the efficiency which they presently lack because of the fragility of wild bait. Mollies are easily cultured and if smaller mollies are further demonstrated to be as effective as larger sizes, production rates can be increased significantly. Investigations directed towards lure design and modification of present baitwell configurations should parallel the development of this new resource.

Acknowledgments

This study was made possible through the cooperation and assistance of the South Pacific Commission. Robert Kearney, Chief, SPC Skipjack Survey and Assessment Program, made the necessary arrangements to have their chartered vessel *Hatsutori Maru* incorporate sea testing of mollies into their schedule. My appreciation to Jean-Pierre Hallier, SPC Scientist, who provided immeasurable help and information during the cruise. The mollies used in these tests were reared under grants from National Marine Fisheries Service, NOAA, U.S. Department of Commerce, and the American Samoa Government. Wayne Baldwin of the Hawaii Institute of Marine Biology (University of Hawaii) gave me much needed technical assistance, logistical support, and overall encouragement. Tanks used to transport the mollies were kindly loaned to me by the Honolulu Laboratory of the Southwest Fisheries Center, NMFS.

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Evaluation of a Bypass System for Juvenile Salmonids at Little Goose Dam

JERREL R. HARMON and DONN L. PARK

ABSTRACT—During the spring of 1978, the National Marine Fisheries Service, under contract to the U.S. Army Corps of Engineers, evaluated a new system for bypassing juvenile chinook salmon, Oncorhynchus tshawytscha, *and steelhead trout,* Salmo gairdneri, *from turbine intakes at Little Goose Dam on the Snake River. The criteria pertaining to orifice size (8-, 10-, or 12-inch diameter); placement (north, south, or both); and lighting (on or off) were examined. Recommendations included: 1) 8- or 10-inch diameter inserts to reduce orifice size (and conserve water) when bypassing chinook salmon and 2) 12-inch diameter lighted orifices in the north and south ends of the upstream walls of the bulkhead slots when bypassing steelhead trout.*

Introduction

Major dams on the Columbia and Snake Rivers incorporate fish bypass systems to protect fingerling salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdneri*, during their downstream migration (Bentley and Raymond, 1969; Park and Farr, 1972; Smith and Farr, 1975; Matthews et al., 1977). These systems employ submerged orifices to provide fish with egress from Turbine gatewells where fish either accumulate naturally or are diverted by fish screens in the turbine intakes. The National Marine Fisheries Service, under contract to the U.S. Army Corps of Engineers, has been conducting research on fingerling bypass systems for several years in an attempt to improve efficiency.

In the existing system at Little Goose Dam on the Snake River (Fig. 1), the majority of fingerlings entering the turbine intakes are diverted into gatewell slots by traveling screens. A vertical barrier screen further confines fingerlings to the bulkhead slots of the gatewells (Smith and Farr, 1975). Single 6-inch diameter submerged orifices in the north corner of the upstream walls of each bulkhead slot provide egress from the gatewells but are incapable of adequately passing large numbers of fingerlings from the slots in a timely manner.

In 1978, changes in the generating capacity of Little Goose Dam compounded the inadequacies of the fingerling bypass system. From 1971 to 1977, only three generating units were in operation, but in 1978 three more

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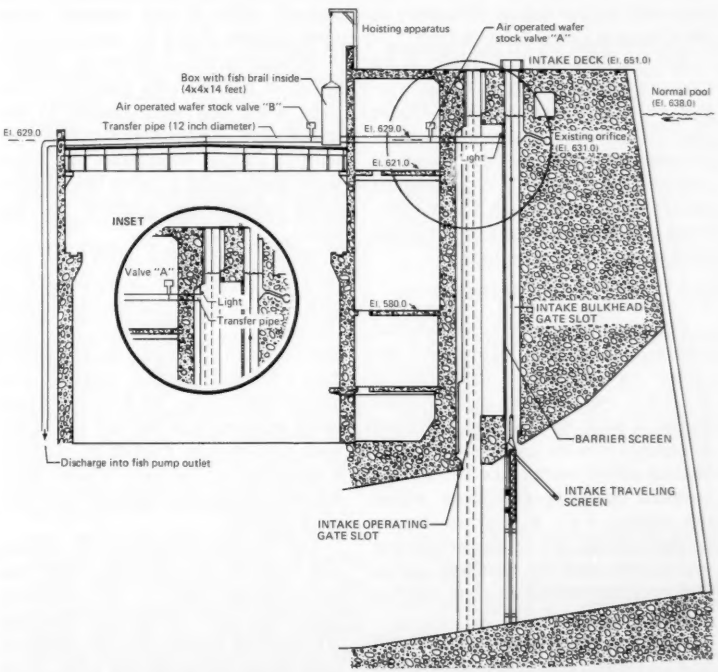

Figure 1.—Experimental orifices and trapping facility as operated in the intake bulkhead gate slot and operating gate slot (see inset) at Little Goose Dam.

units were added. With three additional units in operation, orifice attraction velocities within the bypass system were substantially reduced, resulting in large accumulations of fingerlings in the gatewells. Compounding the problem, excess water (spilled when only three units were operational) is now used for the generation of power through the three additional generating units. Consequently, this makes even more fish available for diversion into gatewells by traveling screens, resulting in an even larger accumulation of fingerlings.

A more recently constructed bypass system at Lower Granite Dam on the Snake River has two 8-inch diameter submerged orifices in each corner of the upstream walls of the bulkhead slot (Matthews et al., 1977). This bypass system passes fish with a high degree of efficiency. Moreover, descaling and injury to fingerlings are less than half of that observed at Little Goose Dam. Consequently, we feel that the bypass system at Little Goose Dam can be improved to pass fish as effectively as the system at Lower Granite Dam.

The purpose of this study is to evaluate criteria for a new bypass system to be installed at Little Goose Dam. Specifically, we evaluated orifice diameter, lighting, and placement in turbine intake gate slots. We conducted tests from 8 April through 3 May 1978, using naturally migrating chinook salmon and steelhead smolts.

Methods and Materials

Figure 1 illustrates the experimental orifices and trapping facility. An improved traveling screen (Matthews et al., 1977) was installed in the turbine intake to guide downstream migrating fingerlings into the test gatewell (1-A). Special efforts were made to maintain standard operating conditions within the turbine; i.e., a uniform turbine generating load of 155 megawatts was maintained, and the traveling screen was operating while all tests were in progress.

Existing orifices were blocked off and the submerged orifices to be tested were located in fingerling transfer pipes near each corner on the downstream wall of the gatewell at an elevation of 629 feet (all elevations are designated as feet above mean sea level). The two 12-inch diameter fingerling transfer pipes were capable of holding 8- or 10-inch diameter orifice inserts at their gatewell entrances. Thus, three orifice pipe sizes were available for testing. Illumination for the orifices was provided by 75-watt swimming pool lights.

Fish were collected at trap-hoppers located outside the powerhouse roof. A fish brail in the traps allowed hoisting of fingerlings to the intake deck for inspection and enumeration. Excess water was eliminated at the holding boxes and carried to the tailrace level by pipe.

Water flow in the trap-hoppers was regulated by two air operated wafer valves (Fig. 1). Water levels in the trap-hoppers were maintained 2 feet lower than the water level in the gatewell. This provided a stable velocity of 12 fps from the orifice entrances through the transfer pipes into the traps. During testing, valve A was operated wide open but was closed for approximately 5 minutes every 2 hours to restrict egress of fish from the gatewell to the traps while fish were brailed to the intake deck. Valve B was adjusted to remove excess water from the traps while maintaining a 2-foot head differential between the gatewell and the traps.

Smolts used in this study were obtained by dipping bulkhead slots other than slot 1-A with a gatewell dip basket (Swan et al., 1979). The fish were transferred to a marking facility where they were anesthetized, marked, and held in stock tanks for 4 hours before being released into the test slot. Chinook salmon were marked by excising a portion of their pectoral or pelvic fins. Steelhead trout were tattooed with colored pigment.

The first test series involved passing fish with the transfer pipes from the bulkhead slot (Fig. 1). The following tests were made using approximately 200 chinook salmon and 200 steelhead trout (three replicates per test): 1) 8-inch diameter north and south orifices operated with lights, 2) 10-inch diameter north and south orifices operated with lights, 3) 10-inch diameter north and south orifices operated without lights, 4) 10-inch diameter north orifice operated with lights, and 5) 12-inch diameter south orifice operated with lights.

To begin a test the bulkhead slot was dipped clean of fish at 1530 hours, and marked fish were introduced via a hose into the center of the bulkhead slot at the 20-foot depth at 1600 hours. During the 24-hour test period each trap was emptied every 2 hours to count marked and naturally entering migrants. Since the vertical barrier screen was intact during these tests, all fish were removed from the bulkhead slot with the gatewell dip basket after each test replicate.

To evaluate the passage efficiency of the orifices, marked fish from the traps plus those marked fish that were recovered in the gatewell at the end of a test were assumed to be the total number of fish available for passage. The pasage efficiency was determined by dividing the number of marked fish removed from the orifice traps by the total number of marked fish available for passage.

Recovery of marked fish was also compared with the recovery of naturally entering (unmarked) migrants. The passage efficiencies of the orifices for the naturally entering fish were calculated in the same manner as used for marked fish.

The second test series involved passing smolts from the operating gate slot when the upper two panels of the vertical barrier screen between the bulkhead and operating slots were removed (Figure 1 inset). The associated transfer pipes were also removed. This test was conducted to determine if fish would voluntarily swim from the bulkhead slot to orifices in the downstream wall of the operating gate slot. The bulkhead slot was darkened during these tests.

Since a portion of the barrier screen was removed, gatewells were not dipped because the operating gate slot was not accessible; therefore, movement of unmarked fish could not be measured. Passage efficiencies were

determined by dividing the number of marked fish recovered in the traps by the number introduced. Marked fish data were used to compare results of bulkhead and operating gate slot tests. The same series of tests were scheduled for the operating gate slots that were used for bulkhead slot tests.

On 19 May 1978, directional current readings were made in the three intake bulkhead slots (1-A, 1-B, 1-C) of unit one with a Sevonious-type[1] directional current meter. Readings were taken at an elevation of 629 feet, which corresponds to the depth of the submerged test orifices. Three measurements were made in each slot while the turbine was operated in the standard operating mode. During the measurements the orifices were closed, and measurements were taken near the entrances to the orifices. These measurements were taken to compare water flow characteristics in the A, B, and C slots to determine if current directions at the orifice level might have an effect on fish movement to either side of the gate slot or on fish passage through the orifices.

Table 1.—Passage rate of test (marked) and naturally entering chinook salmon and steelhead through various combinations of 8-, 10-, or 12-inch diameter orifices installed in the downstream side of the bulkhead slot (1-A) at Little Goose Dam.

Species and test condition	Combined number of marked fish released[1]	Passage rate[2] for marked fish (%)			Passage rate[2] for natually entering fish (%)		
		North orifice	South orifice	Both orifices	North orifice	South orifice	Both orifices
Chinook salmon							
North and south 8-inch diameter orifices, lighted	509	39	27	66	61	12	73
North and south 10-inch diameter orifices, lighted	[3]826	37	37	74	47	25	72
North and south 10-inch diameter orifices, dark	626	29	25	54	27	13	40
North 10-inch diameter orifice, lighted	596	38	—	—	62	—	—
South 12-inch diameter orifice, lighted	622	—	59	—	—	63	—
Steelhead							
North and south 8-inch diameter orifices, lighted	575	24	17	41	31	10	41
North and south 10-inch diameter orifices, lighted	[3]694	35	12	46	38	18	56
North and south 10-inch diameter orifices, dark	595	30	16	46	28	23	51
North 10-inch diameter orifice, lighted	471	26	—	—	29	—	—
South 12-inch diameter orifice, lighted	534	—	25	—	—	23	—

[1]Three replicates.
[2]Passage rate equals number of recoveries divided by number released.
[3]Four replicates were used. The turbine was shut down during one test for 2 hours. However, it did not appear to affect recovery rate; therefore, the data were used.

Results and Discussion

The authors have made no attempt to prejudge an acceptable passage rate for an orifice system. However, during the peak of the downstream migration, over 10,000 fingerlings have been removed from a single gatewell after a 24-hour accumulation. It would appear that a fish passage rate of at least 75 percent of the 24-hour accumulation is necessary if large accumulations of juveniles are to be avoided in gatewells.

Fish Passage Through Orifices Placed in Bulkhead Slot

The results of our tests are summarized in Table 1. The data do not provide clear evidence for an optimum orifice passage arrangement. Some general observations can be made however, that may lead to an optimum arrangement: 1) Two orifices provided the most satisfactory passage efficiencies; 2) lighted orifices definitely increased passage rates for chinook salmon but appeared to be of little value for steelhead trout; 3) both species preferred the north orifice when offered a choice for passage; and 4) relatively high passage rates, from 59 to 63 percent, were achieved for chinook salmon with a single 12-inch diameter orifice (passage rates for steelhead trout through the single 12-inch diameter orifice were lower—23-25 percent).

Throughout the tests steelhead trout showed lower passage rates than did chinook salmon. We speculate that smoltification of chinook salmon may have been more advanced during the test period than of steelhead trout (i.e., tests were run near the peak of the chinook salmon migration, whereas testing was completed prior to the migration peak of steelhead trout). This could account for greater chinook salmon movement through orifices and a subsequently higher recovery rate.

Similar orifice testing conducted at Lower Granite Dam in 1976 showed passage rates for the north orifice to be superior to the south orifice and that in all cases lighted orifices were best[2]. The study showed that the passage efficiency of a single 8-inch diameter lighted north orifice was as efficient as two 6-inch diameter lighted orifices. Studies completed at Bonneville Dam indicated that the passage efficiency for two 8-inch diameter lighted orifices was nearly as good as two 12-inch diameter lighted orifices[3].

Our study indicates that satisfactory passage rates are realized with 8- or 10-inch diameter orifices for chinook salmon, whereas 12-inch diameter orifices would be better for adequate

[1]Mention of trade names or commercial products or firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[2]George A. Swan, National Marine Fisheries Service, Big Pasco Industrial Park, Bldg. 900, Pasco, WA 98301, personal commun.

[3]Long, C. W., R. F. Krcma, and T. E. Ruehle. 1977. Development of a system for protecting juvenile salmonids at the second powerhouse at Bonneville Dam. Progress 1976. Final Report of Research to U.S. Army Corps of Engineers, Contract DACW57-76-F-0512. Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Northwest Fish. Center, Seattle, Wash. Processed Rep., 15 p.

steelhead trout passage. Because the chinook salmon migration normally precedes the steelhead trout migration at Little Goose Dam, the smaller inserts could be used during the chinook salmon run, and orifice size could be enlarged by the removal of these inserts during the steelhead trout movement. This scheme would allow the conservation of water (i.e., much less water would pass through the 8-inch diameter orifices than through the 12-inch diameter orifices) while maintaining an adequate fish passage rate during the entire salmon and steelhead outmigration. In actual practice, orifices should be drilled through the upstream wall, rather than using the downstream wall as in our test situation.

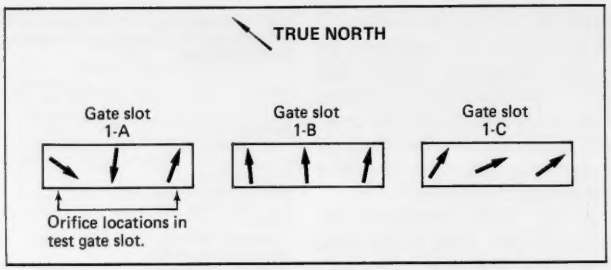

Figure 2.—Directional current readings taken at elevation 629 feet (orifice level) in the intake bulkhead gate slots of unit one at Little Goose Dam.

Fish Passage Through Orifices Placed in Operating Gate Slot

We planned to complete the same experimental design in the operating gate slot that we used for the bulkhead slot, but the tests were terminated after completing the replicated tests with 8-inch diameter north and south lighted orifices. The passage rate through the orifices was only 1 percent for chinook salmon and 4 percent for steelhead trout. It was apparent that the removal of the upper two panels of the barrier screen to allow fingerlings access to the orifices placed in the downstream wall (Figure 1 inset) created an escape route back to the turbine intake. When we dipped the bulkhead slot following the tests, no fish were recovered and very few naturally entering migrants were detected.

Directional Currents in Bulkhead Slot

We have shown that in all the tests where a choice of north or south orifices were offered, both chinook salmon and steelhead trout preferred the north orifice. Our only clue to a reason for this preference was indicated by surface currents observed in the gatewells.

In the test gatewell (Fig. 2, 1-A), the current at the orifice level was oriented toward the north orifice and away from the south orifice. By contrast, the currents were oriented away from similar orifice locations in gatewells 1-B and 1-C (Fig. 2). If currents are a factor in the selection of the north orifice in 1-A, then a more equal distribution of fish to both orifices could be expected in 1-B and 1-C. However, if the orifices are placed in the upstream wall of the gate slot in a future installation, then most fish may be expected to use the south orifice in the test gatewell (1-A). This rationale presents a strong argument for a placement of two orifices per gatewell for any future orifice system.

Conclusions

Construction of an orifice system in the operating gate slots is not practical. To gain access to the orifices, the upper two panels of the vertical barrier screen must be removed and this creates an escape route for fish back to the turbine intakes.

Current directions may have an effect on fish movement through orifices in gatewells. Because current directions vary in different gatewells, two orifices should be used to realize satisfactory passage.

Lighted orifices increase passage rates for chinook salmon but appear to have little effect on passing steelhead trout.

A complete orifice system at Little Goose Dam requires north and south 12-inch diameter lighted orifices in the downstream walls of the bulkhead slots.

To conserve water while maintaining adequate fish passage, 8- or 10-inch diameter inserts can be used during the chinook salmon migration whereas the 12-inch diameter orifices should be used during steelhead trout movement.

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Recent Observations of a Large Eddy in the Gulf of Alaska

R. K. REED

ABSTRACT—Data in September 1978 revealed an intense clockwise eddy in the Gulf of Alaska which appeared to form as a result of vorticity conservation in the flow near Pratt Seamount. The existence of many large seamounts in this region suggests that well-developed eddies may be common. These circulation features are important to resource assessment because the movement of food organisms may be modified.

Introduction

On 26 June 1978 the Seasat-A satellite was launched to evaluate and demonstrate the potential of its sensors to provide assessments of ocean waves, winds, temperature, and currents. The availability of this information in real time could establish a new era in providing services of value to fisheries, shipping, weather forecasting, and other activities. As part of efforts to obtain "ground truth" for Seasat-A, a suite of measurements was carried out by the NOAA ship *Oceanographer* in the Gulf of Alaska and seaward of Vancouver Island in September 1978, which fortuitously occurred before the satellite system's demise from a power failure in October 1978. The *Oceanographer* obtained only limited information on circulation in the region, but the data did reveal a well-developed eddy in the flow, which appeared to be induced by bottom topography. These observations and their implications are the subject of this article.

Distributions and Circulation

The long CTD (conductivity/temperature/depth) section (stations 19-34) shown in Figure 1 was taken to assess the northward flow into the Gulf of Alaska. While examining the data aboard ship, a strong reversal in the density slopes near Pratt Seamount was noted, and a short section (stations 36-41) was added in an effort to define the limits of this feature.

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Figure 2 presents vertical sections of sigma-t (density minus one times 10^3) for both of the CTD sections occupied in early September. The northernmost section (Fig. 2a, stations 19-34) reveals a departure from the general downward slope of isolines; at station 24, just north of Pratt Seamount, the isolines reach their greatest depth and then slope upward and flatten out. On the basis of only this information one would suspect that a clockwise eddy was present in the general northward flow. The feature is well developed from 100 to over 1,000 m, but the signature disappears near the surface. (It should be noted, however, that Surveyor Seamount, between stations 21 and 22, does not seem to affect the density field, probably because its steepest part is downstream of this section.) The second CTD section (Fig. 2b, stations 36-41) indicates a general northward flow with only a slight reversal in slope at mid-depths. Thus the large density perturbation appears to have formed between the two CTD profiles.

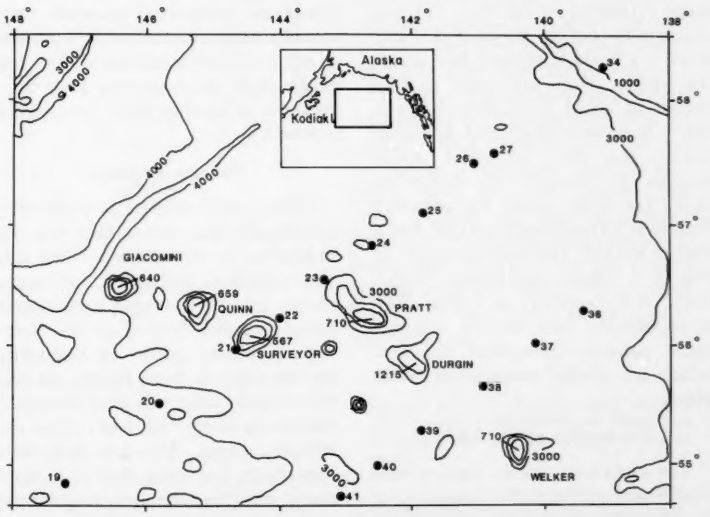


Figure 1.—Location of CTD stations taken by the NOAA ship *Oceanographer*, 4-7 September 1978. The bathymetry is in meters from National Ocean Survey Chart 500, dated November 1976. The insert shows the location of this area in the Gulf of Alaska.

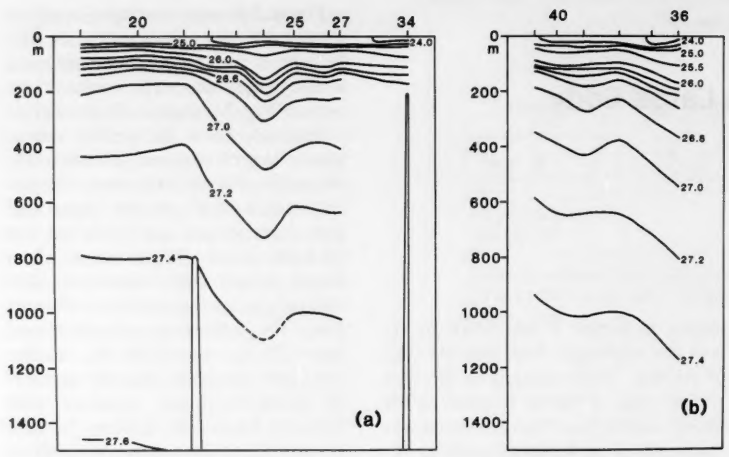


Figure 2. — Vertical sections of sigma-t density ($\mu g/cm^3$): (a) stations 19-34, 4-6 September 1978; and (b) stations 36-41, 6-7 September 1978.

In the absence of direct current measurements, circulation is usually inferred from the geopotential topography; the topography of the sea surface and 500 m, referred to 1,500 m, is shown in Figure 3. (The surface topography was extended inshore to station 34 by consideration of the isopycnal slopes at the deepest common level between stations 27 and 34.) Although the data are rather sparse for an adequate resolution of the flow, two unambiguous features do emerge. First, there is a broad northward flow across the region with maximum surface speeds of about 20 cm/sec. Second, there is a well developed eddy-like feature near Pratt Seamount, which appears to bifurcate the northward flow. The relief across the eddy-like feature at 500 m is less than half that at the sea surface. The features evident in Figure 3 extend appreciably deeper than 500 m, however; the 1,000/1,500-m topography (not shown) indicates weak patterns throughout the area which are similar to those at levels above.

Formation of the Eddy

The clockwise, rotary feature near Pratt Seamount (hereafter referred to as the "eddy" even though the data are insufficient to determine precisely its shape or if streamlines are closed) appears to be generated downstream of CTD stations 36-41. This evidence would certainly suggest that the eddy may form through interaction of the flow with Pratt, and perhaps Durgin, Seamount. Pratt Seamount is a massive feature which could be expected to influence the flow through vorticity constraints, although other aspects of topographic influence on dynamics may be important (Huppert and Bryan, 1976). If vorticity is approximately conserved, clockwise curvature may increase when a northward flow crosses a region of decreasing depth. Thus the existence of the eddy near Pratt Seamount is in keeping with these simple concepts.

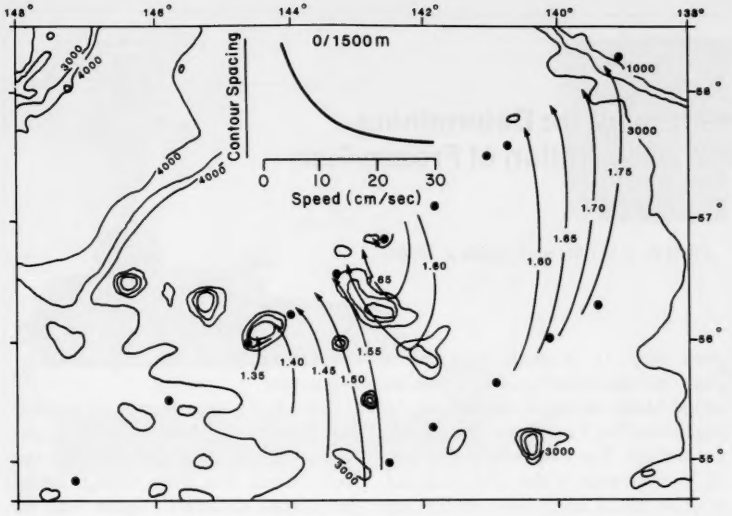
Surface Features

It was noted earlier that the density distribution near the surface was not indicative of the marked relief that was present at mid-depths; obviously though the eddy is a major feature in the surface current field (Fig. 3). Near-surface density slopes are frequently not the same as those below, but this only slightly alters the flow because it reflects the integrated slopes above the reference level. The fact that there appears to be some decay in eddy energy near the surface is in agreement with theory on the vertical scale of obstacle-induced flow (Huppert and Bryan, 1976), however.

Sea surface temperature is the most easily sensed parameter (through ship reports or satellite observations) of potential value to users, and a number of such products are issued on a regular basis (the biweekly temperature maps produced by the National Marine Fisheries Service, Southwest Fisheries Center, La Jolla, Calif., for example). In this instance, however, sea surface temperature (Fig. 4) was not of value as an index of the general surface flow or the eddy; the temperature range across the northernmost CTD section is only 1°C (hardly detectable by satellite radiometers), and the temperature slope between stations 24 and 25 is in the opposite sense to what would be expected for a clockwise eddy. Although satellite imagery does suggest the existence of eddies in the Gulf of Alaska (G. Hufford, National Environmental Satellite Service, Anchorage, Alaska), the energetic eddy described here would not have been detected by these surface measurements.

Implications

From even a cursory examination of a nautical chart or bathymetric map, it is apparent that the eastern Gulf of Alaska has many large seamounts with minimum depths less than 1,000 m. Several of them are shown in Figure 1, but there is another chain of seamounts southeast of Welker Seamount, bounded by Bowie Seamount on the south and



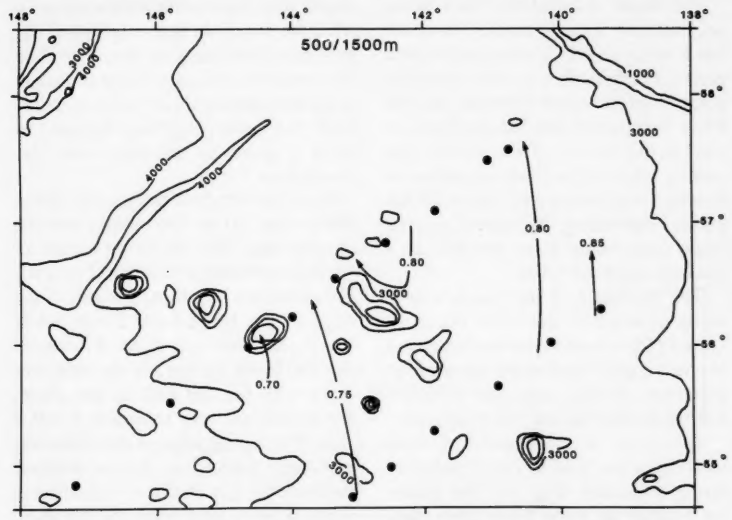


Figure 3.—Geopotential topography (in dyn m) at the sea surface and 500 m, both referred to 1,500 m, 4-7 September 1978.

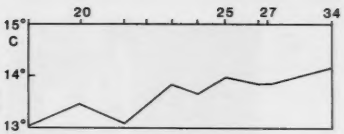


Figure 4.—Sea surface temperature (°C) at stations 19-34, 4-6 September 1978.

Brown Seamount on the north. Many of these features could be expected to affect the northward flow significantly. If vorticity constraints play the dominant role in the topographic interactions with the flow as suggested by the data here, one might expect the generation of numerous clockwise eddies. These features are not readily apparent in most historical data, but the widely spaced observations available do suggest numerous perturbations in the northward flow (Dodimead et al., 1963; Favorite et al., 1976).

Traditionally, fisheries scientists have been especially concerned about the effects of counterclockwise eddies or upwelling zones on the ecosystem because the rising waters may replenish nutrients from below and enhance primary productivity of the upper water. Clockwise eddies should have the opposite effect, but this does not mean that these features should be ignored. These rotary systems are dynamically important, and it is certainly conceivable that they tend to trap food organisms or in other ways interfere with the drift of zooplankton and larvae. Thus the location of clockwise eddies in the Gulf of Alaska should be quite relevant to fisheries assessments. The data presented here, however, suggest that these features can only be reliably defined by subsurface measurements. Rapid XBT surveys and the use of satellite-tracked drifting buoys could perhaps provide useful information at reasonable cost.

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Instrument for Determining Depth of Dehydration of Frozen Fish

JOHN G. CALLAN and JOHN J. RYAN

Introduction

United States Standards for grades of various frozen seafood products include as a quality defect the presence of dehydration. It is considered a quality defect both because product weight is lost and because the surface and thin parts of the fish become irreversibly dry and porous, often making the product unpalatable and unacceptable. This quality defect is exhibited by a white porous appearance and by affected areas that feel relatively dry to the touch.

Most USDC (United States Department of Commerce) voluntary standards for frozen fish products evaluate the degree of the defect by the depth of the dehydration and the area affected. To date, the depth of dehydration has been determined by scraping the dehydrated area with the thumbnail. While this method is as useful as many tests used for determining seafood quality, an investigation to arrive at a more quantitative and more precise method has been made.

This report describes the design, construction, and operation of a dehydration depth gauge to measure the degree of dehydration in frozen seafoods.

Design

The dehydration depth gauge adopts the principle of a hand-operated wood plane (Fig. 1). A small, inexpensive plane was modified by using a heavier gauge blade having a narrow cutting edge extending 1 mm below the plane's flat surface. The extension is $^3/_{16}$ inch (4.76 mm) wide at the lower end and ¼ inch (6.25 mm) wide at the top (Fig. 2A).

The depth of cut of this blade is set accurately by a gauge block. The block has a wide groove 1 mm deep milled across its top surface so that when the plane is set on top of the block and the blade is loosened and moved down to rest on the bottom of the groove, the cutting edge of the blade extension is exactly 1 mm below the bottom of the plane. Tightening the screw on the blade lock holds it in position at a constant depth of 1 mm.

The resistance of the frozen fish to being grooved by the plane blade required a force such that it was necessary to attach a push knob to the plane which permitted a firm grip and effective control facilitating the test procedure.

The parts of the plane that were modified were held to close manufacturing tolerances (Fig. 3). The guides for holding the plane blade from canting were modified to provide a closer tolerance and still allow it to slide freely when the blade locking screw is loosened. This makes it easy to set the blade extension accurately and still keep its position when the locking screw is tightened. The maintenance of close tolerances between the blade guides and the blade, along with the gauge block for depth control, make it possible to remove the blade for cleaning and replacement without any loss of accuracy in the setting. By these modifications, a small plane was transformed into an accurate depth measuring device.

Essentially, the thumbnail method for determining dehydration was designed to determine only whether the dehydration was deep enough to be considered a defect. There was no attempt to obtain a measure of the depth; thus there is no indication as to what the threshold that established the presence of dehydration should be. The best available estimate is that the value of the threshold is about 1 mm. Accordingly, the depth gauge was designed to yield a go/no-go decision with the threshold at 1 mm.

In an intermediate design, the planer blade was left at full width, but the cutting edge was set to cut a path of varied depth from 0 to 2 mm (Fig. 2B). This was done by cutting one side of the edge of the blade back 2 mm while leaving the other side alone. By extending the blade so that its cut side was flush with the flat bed of the plane, the uncut side was extended a full 2 mm. The cutting edge of the blade was uniformly marked so that an accurate measure of the depth of dehydration could be made up to twice the threshold depth. However, this was not possible for several reasons: 1) It required too much force to cut wide strips of frozen fish tissue; 2) the V-notches in the plane blade produced an irregular surface which distorted the light being reflected from the clean frozen fish flesh and from the dehydrated flesh fibers; and 3) sharpening the plane blade must be done in a holding jig to maintain some of the parameters that must not be changed. The results of this part of the study forced the decision to reduce the width of the cutting edge and

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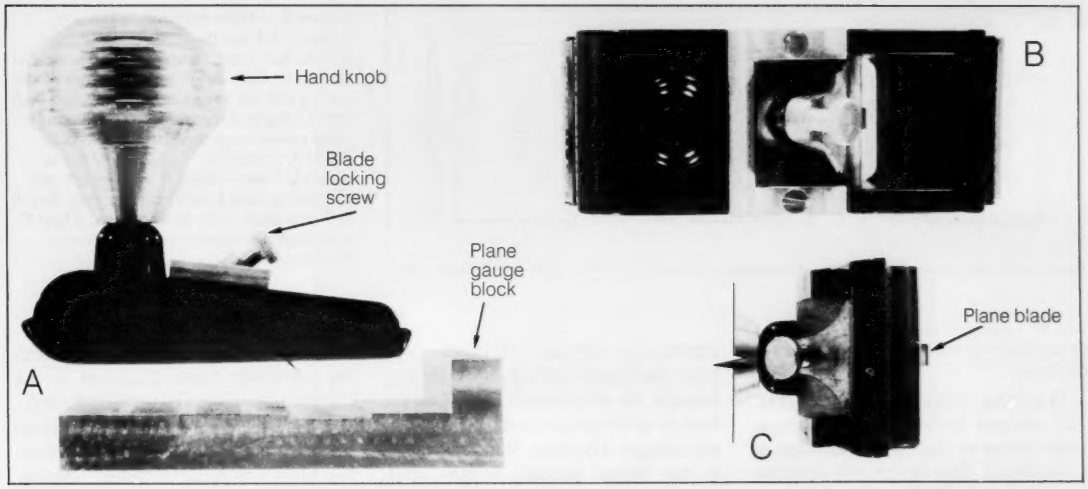

Figure 1.—The dehydration depth gauge: A) Side elevation shows hand knob, blade locking screw, and plane gauge block for setting blade extension to 1 mm; B) plan view of plane gauge with hand knob removed; C) end view of plane blade.

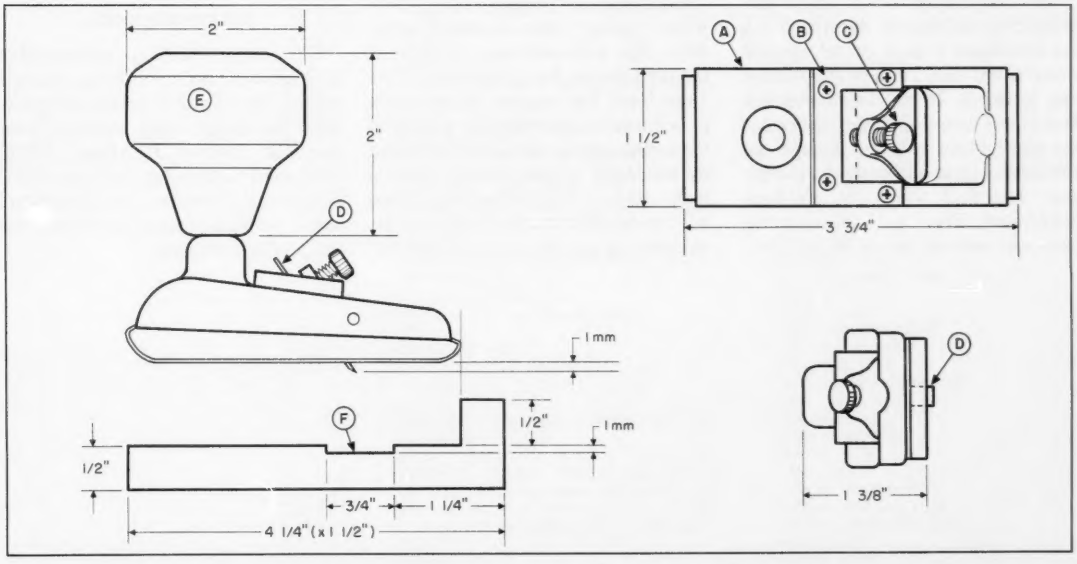

Figure 2.—Plane gauge construction and accessories: A) Plan view of plane, B) blade guide to keep blade from canting, C) blade locking screw, D) blade ($^3/_{16}$ inch wide) which extends 1 mm beyond bottom, E) hand knob for pushing and guiding the plane, F) gauge block for setting blade extension exactly to 1 mm.

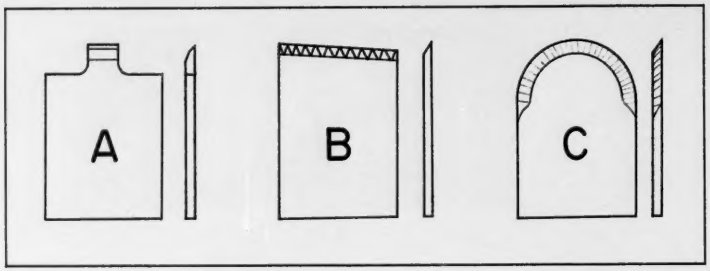

Figure 3.—Three experimental blade designs. All had the same body width, length, thickness, tolerances, and tempered tool steel. Only the shape and width of the cutting end has been altered to obtain a path that is clear and readable without having to exert excessive pressure to cut the path. Blade A is narrow, $^3/_{16}$ inch, and set to protrude 1 mm. Blade B was angled and notched to cut a 1-inch track varying from 0 to 2 mm deep in the frozen flesh. Blade C was shaped to simulate an inspector's thumbnail.

to attempt to obtain only a go/no-go decision.

In another intermediate design (Fig. 3C), a planer blade was shaped nearly semicircular to duplicate the shape of a thumbnail. This design was not practical because it required too much force to use. This raised the question as to the ability to push a thumbnail through dehydrated flesh, and it was concluded that the thumbnail did not cut a uniform path of 1 mm depth but that it cut at an uneven depth, most of the times at less than 1 mm.

Operation

The dehydration depth gauge tells whether the surface of the frozen fish has developed a layer of dehydration which is less than 1 mm or more than 1 mm in depth. If the dehydrated fish flesh is less than 1 mm deep, the end of the plane blade will cut through the dehydrated layer and enter the acceptable clear flesh which has not been dehydrated. The "go" criterion has been met and the frozen block is acceptable for shipping. If, on the other hand, the blade does not cut all the way through the dehydrated layer then the bottom of the groove will appear white and spongy. The plane blade cuts a path in the frozen product 1 mm deep. Examination of the bottom of the path will disclose three different conditions:

1) A clear, semitransparent product with no spongy dehydrated material included. This condition is "go", meaning that the frozen product has passed the test, and requires no decision by the inspector other than cutting three or four more confirmatory test paths.

2) A mixture of sections of clear, semitransparent product along with white, spongy spots occurring regularly. This indicates that the depth of the dehydration has progressed to the 1 mm limit. This requires an estimation to be made to determine the percent of the surface area of the product affected by this depth of dehydration. Several paths, three or four inches long should be cut to confirm the depth of the dehydration and the extent of the surface area affected. If that area exceeds the allowable limit described in the standard, then the product fails the test.

3) A white spongy appearance at the bottom of all paths cut for inspection after making confirmatory checks. Again, there should be no question of what decision should be made. This is a "no-go" condition and the product fails the test.

In tests conducted at the Gloucester Laboratory, the depth gauge performed so well and was such an improvement over the thumbnail method that it will be the recommended procedure for the dehydration test in all future standards and Inspectors' Instructions.

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The authors wish to acknowledge their gratitude to the following persons, without whose collaboration and assistance this paper could not have been prepared. Michael J. Allsup, NEFC Gloucester Laboratory, for his photographic contributions, and Brad Marques, Northeast Inspection Office, for testing the instrument.

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Marine Fisheries Review publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under completed NOAA Form 25-700.

Manuscripts must be typed (double-spaced) on high-quality white bond paper and submitted with two duplicate (but not carbon) copies. The complete manuscript normally includes a title page, a short abstract (if needed), text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1½-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

Style

In style, *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 6, "A List of Common and Scientific Names of Fishes from the United States and Canada," third edition, 1970. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

Tables and Footnotes

Tables and footnotes should be typed separately and double-spaced. Tables should be numbered and referenced in text. Table headings and format should be consistent; do not use vertical rules.

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Title the list of references "Literature Citations" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, the year and month and volume and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted. Include the title, author, pagination of the manuscript or report, and the address where it is on file. For personal communications, list the name, affiliation, and address of the communicator.

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Authors must double-check all literature cited; they alone are responsible for its accuracy.

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All figures should be clearly identified with the author's name and figure number, if used. Figure legends should be brief and a copy may be taped to the back of the figure. Figures may or may not be numbered. Do not write on the back of photographs. Photographs should be black and white, 8- × 10- inches, sharply focused glossies of strong contrast. Potential cover photos are welcome but their return cannot be guaranteed. Magnification listed for photomicrographs must match the figure submitted (a scale bar may be preferred).

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